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D.R. MacDonald,
Editor

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Jack MacIsaac
Minister

John J. Laffin, D.Eng. FEIC, P.Eng.
Deputy Minister

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Editor: D. R. MacDonald

Word Processing: B. L. MacDonald and B. S. Boutilier

Cartography: J. Campbell
W. Burt
P. Belliveau
G. MacDonald
C. Phillips
P. Fraser
R. MacPherson
E. Limpert
J. Webster
J. DeWolfe

Photography: C. Murphy
R. Morrison

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1701 Hollis Street, 3rd Floor
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TABLE OF CONTENTS

Page

Foreword vii

MINERAL DEVELOPMENT DIVISION

Mineral Exploration Monitoring Activities - *P. D. McCulloch and J. M. McMullin* 1

Drill Core Libraries - *J. D. Langille* 9

MINERAL RESOURCES DIVISION

The Southwest Nova Scotia Tin Domain, Yarmouth County, Nova Scotia: Implications for Tin Metallogeny in the Meguma Terrane, Nova Scotia - *D. J. Kontak, G. A. O'Reilly and A. K. Chatterjee* 13

A ^{40}Ar/^{39}Ar Geochronological Study of Metamorphic and Igenous Rocks of the Liscomb Complex, Southern Nova Scotia - *D. J. Kontak, A. K. Chatterjee, P. H. Reynolds and K. Taylor* 33

Gold Anomalies in the -230 Mesh Fraction of Bulk Stream Sediment Samples from Northern Nova Scotia - *R. F. Mills* 41

EXTERNAL ABSTRACTS AND CONFERENCE PRESENTATIONS

Recent Advances in the Geology of the South Mountain Batholith: Anatomy and Origin of a Batholith - *M. A. MacDonald, M. C. Corey, L. J. Ham, R. J. Horne and A. K. Chatterjee* 49

Geology and Mineralization Associated with the Tobeatic Lake Shear Zone, Southwestern Nova Scotia - *M. C. Corey, R. J. Horne and P. K. Smith* 50

Petrographic and Geochemical Evidence for a Hypogene Origin of Grantite-Hosted, Vein-Type Mn Mineralization at the New Ross Mn Mines, Lunenburg County, Nova Scotia - *G. A. O'Reilly* 51

Emplacement of the South Mountain Batholith: Structural and Intrusive Considerations - *R. J. Horne, M. C. Corey, L. J. Ham and M. A. MacDonald* 53

Use of Nonparametric Ranking Statistics to Identify Magmatic and Post-Magmatic Processes in the Eastern South Mountain Batholith, Nova Scotia, Canada - *M. A. MacDonald and D. B. Clarke* 54

New Palynological Age Dates, Zonations, and Stratigraphy in the Permo-Carboniferous Strata of the Cumberland Basin, Nova Scotia - *R. J. Ryan, R. C. Boehner, J. Calder and G. Dolby* 60

Comparison of Apatite Fission Track Length Spectra and Organic Maturation Indicators in the Maritimes Basin, Eastern Canada - *R. J. Ryan, A. M. Grist, M. Zentilli and R. C. Boehner* 61

Rapid Late-Glacial Climatic Fluctuations in Atlantic Canada - *R. J. Mott and R. R. Stea* 62

New Quaternary Age Dates in Atlantic Canada - *R. R. Stea and R. J. Mott* 63

Wisconsinan Chronology in Eastern Canada: Long or Short? - *R. R. Stea and R. J. Mott* 64

Pre-Mesozoic Terranes in Circum-Atlantic Phanerozoic Orogens - *J. D. Keppie and R. D. Dallmeyer* 65

Northern Appalachian Terranes: Their Nature and Accretionary History - *J. D. Keppie* 67

1:5,000,000 Map of the Pre-Mesozoic Terranes in Circum-Atlantic Phanerozoic Orogens - *J. D. Keppie and R. D. Dallmeyer* 69

1:5,000,000 Map of Precambrian and Paleozoic Terranes in Circum-Atlantic Phanerozoic Orogens - *J. D. Keppie and R. D. Dallmeyer* 70

Accretionary History of Pre-Mesozoic Terranes in Circum-Atlantic Phanerozoic Orogens - *J. D. Keppie and R. D. Dallmeyer* 72

Avalon Composite Terrane of Northern Appalachians: Possible Correlatives - *J. B. Murphy, J. D. Keppie, R. D. Nance and J. Dostal* 74

Reassessment of Terranes in the Avalon Composite Terrane of Atlantic Canada - *J. B. Murphy, J. D. Keppie, R. D. Nance and J. Dostal* 76

Episodic Proterozoic-Cambrian Plutonism in the Avalon Composite Terrane in Nova Scotia: Constraints from ^{40}Ar/^{39}Ar Hornblende Ages - *J. D. Keppie, R. D. Dallmeyer and J. B. Murphy* 77

Neotectonic and Paleoseismic Phenomena Along the North Shore of the Minas Basin, Nova Scotia - *T. R. Stokes and J. D. Keppie* 78

Implications of ^{40}Ar/^{39}Ar Hornblende Ages from Late Proterozoic-Cambrian Plutons in the Avalon Composite Terrane of Nova Scotia - *J. D. Keppie, R. D. Dallmeyer and J. B. Murphy* 79

Tectonic Map of Pre-Mesozoic Terranes in Circum-Atlantic Phanerozoic Orogens - *J. D. Keppie and R. D. Dallmeyer* 80

Tectonic Map of Pre-Mesozoic Terranes in Circum-Atlantic Phanerozoic Orogens: A 1:5,000,000 Compilation - *J. D. Keppie and R. D. Dallmeyer* 82

Reconnaissance and Detailed Geochemical Surveys for Gold in Eastern Nova Scotia Using Plants, Lake Sediment, Soil and Till - *C. E. Dunn, W. B. Coker and P. J. Rogers* 83

Comparative Spatial Analysis of Anomalies Derived from Biogeochemical, Lake Sediment and Airborne Geophysical Data, Eastern Nova Scotia - *H. George, G. F. Bonham-Carter, C. E. Dunn and P. J. Rogers* 84

Geochemical Mapping: Comparison of Regional Lake Sediment and Biogeochemical Surveys, Eastern Shore, Nova Scotia, Canada - *P. J. Rogers, G. F. Bonham-Carter and C. E. Dunn* 85

Geochemical Exploration Using Micro-Computer-Based Systems with Reference to Nova Scotia - *P. J. Rogers* 88

APPENDIX I

Nova Scotia Department of Mines and Energy Publications Available for Purchase 91

FOREWORD

This annual Report of Activities contains reports of field and analytical studies carried out or coordinated by the Nova Scotia Department of Mines and Energy. Most of the projects form part of a five-year, $26 million Canada - Nova Scotia Mineral Development Agreement that was implemented in 1984. A great deal of new information on the geology and mineral resources of the Province has been collected. The Agreement, together with other programs, was designed to promote and encourage the discovery and development of Nova Scotia's mineral resources. Although projects carried out during the Agreement were of special interest to individual prospectors and other members of the mining community, the data collected from 1984-1989 are also very useful to municipal planners, hydrologists, soil scientists, environmentalists, foresters, health scientists, those involved in the construction industry, and others.

A variety of mineral resources have been examined and results from this work are described in this report. Regional geological and geochemical surveys to evaluate the mineral potential over large areas have also been conducted. These activities expand the information base available to the resource sector and help strengthen our resource industries.

I commend this publication to your attention on behalf of the staff of the Department of Mines and Energy. This report presents the considered interpretations and conclusions of research at an advanced stage of project development. Our intention is to provide information that will help you understand Nova Scotia's geology and mineral resource potential.

Jack MacIsaac
Minister of Mines and Energy

MINERAL EXPLORATION MONITORING ACTIVITIES

P. D. McCulloch and J. M. McMullin

INTRODUCTION

Monitoring of mineral exploration activity in Nova Scotia is the responsibility of the Resource Geology Section of the Mineral Development Division. Staff assigned to this program consist of a regional geologist and a project geologist based in the regional office at Stellarton, Pictou County.

The monitoring process covers all exploration activities in the Province and includes regular visits to company offices and exploration sites, liaison with industry personnel and reviews of current assessment reports and other material submitted by industry. Direct liaison with industry allows the Department to maintain an awareness of current exploration activities throughout the Province. Problems and difficulties that may need to be addressed by the Department are identified and assistance or advice is provided if necessary. A statistical survey of exploration expenditures is compiled annually to obtain data on costs related to the various sectors of the mineral industry in Nova Scotia.

In addition, all drill core generated in the Province by mining exploration companies is recorded as part of the monitoring process. This core may be recovered for the Drill Core Library in Stellarton when no longer required by the companies.

MINERAL EXPLORATION ACTIVITY IN 1989

Mineral exploration expenditures in Nova Scotia were lower in 1989 following a downturn in exploration activity that began in 1988. Exploration expenditures for 1989 are estimated at $29 million, $20 million less than the record $49 million spent in 1988 but still well above the average expenditure levels of the 1970s and early 1980s (Fig. 1). Exploration for gold continued to account for most of the work in the Province with the remainder focused on industrial minerals, base metals and coal (Table 1).

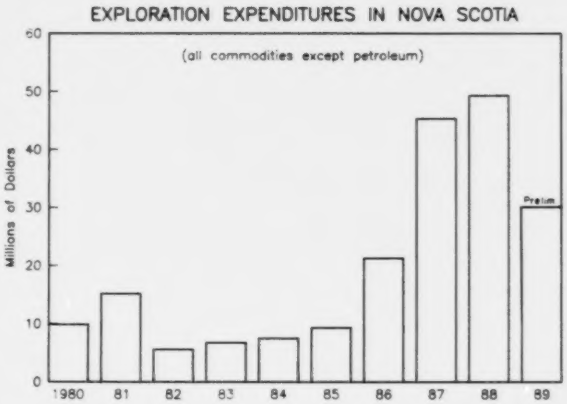

Figure 1. Exploration expenditures in Nova Scotia, 1980-1989.

The decrease in exploration expenditures was due primarily to a significant reduction in gold exploration in the Province. This can be attributed to several factors including the completion of a number of exploration programs as part of the normal exploration cycle, the continued weakness in the price of gold, and the difficulties experienced by many of the junior companies in raising financing. In addition, the failure of several gold properties to be advanced beyond the development stage has eroded investor confidence.

Preliminary figures for the total number of general claims staked in 1989, including both exploration and development licenses, show a decrease of 56% from the previous year to 16,585. The number of claims staked for salt, potash and coal remained low and essentially unchanged from 1988. A total of 17,948 claims for all commodities were in effect at the end of 1989 represented by 685 exploration, development, coal, salt and potash, tailings, and special licenses covering an area of 717,920 acres (1121 square miles or 2902 square kilometres), approximately 5% of the total area of the Province. An additional 12,500 claims remained closed to exploration as a result of the uranium moratorium (781 square miles or 2023 square kilometres).

Table 1. Details of exploration activity in Nova Scotia, 1981-1989. Parentheses around uranium claims indicate ground under alienation due to the uranium moratorium.

	1981	1982	1983	1984	1985	1986	1987	1988	1989
Total Exploration Expenditures ($)	14,607,662	5,552,675	6,500,000	7,300,000	9,000,000	21,000,000	45,000,000	49,000,000	29,000,000
Total Licenses Issued (all categories)	1,952	1,298	1,350	1,049	1,031	1,282	1,989	1,532	685 (est.)
Claims in Good Standing:									
General	68,863	39,626	40,630	25,858	27,636	35,661	53,860	37,371	16,585
Special License	NA	NA	NA	NA	NA	27	445	149	525
Coal	4,880	3,072	4,565	3,584	3,584	1,200	1,200	2,829	606
Salt and Potash	5,225	1,065	505	1,257	830	306	192	232	232
Tailings	NA	NA	NA	379	375	375	0	0	0
Uranium	6,225	(12,500)	(12,500)	(12,500)	(12,500)	(12,500)	(12,500)	(12,500)	(12,500)
Total (excluding closures)	85,193	43,763	45,700	30,078	32,425	37,569	55,697	40,581	17,948
Total Area Held Under License (acres)	3,407,720	1,750,520	1,828,000	1,243,120	1,297,000	1,502,760	2,227,880	1,623,240	717,920
Work Reported for Licence Renewals ($)	8,441,270	4,107,273	4,200,210	2,625,666	2,389,351	9,954,013	26,905,676	29,612,888	31,333,645
Number of Assessment Reports Received	157	124	188	140	108	154	271	406	303

Approximately 244 companies and individuals held exploration interests (licenses or options) in the Province in 1989 including 22 major, 24 junior and 39 private companies (Tables 2 and 3). Several mining lease holders carried out additional exploration on their leases or on unclaimed ground where specific commodities did not require licenses (e.g. limestone, gypsum). Organizations actively engaged in exploration and development work during 1989 included 18 major, 15 junior and 11 private companies as well as a number of individuals.

EXPLORATION AND DEVELOPMENT ACTIVITIES

Gold

Exploration for gold continued to highlight exploration activities for metallic minerals during 1989 with interest continuing to be focused on the historic gold mining districts of Halifax and Guysborough Counties in the southern mainland area of the Province. Work was concentrated on a detailed evaluation of several known gold occurrences hosted by the Cambro-Ordovician metasedimentary rocks of the Meguma Group. Gold exploration was also carried out on Cambrian and Hadrynian rocks in the highland areas of northern Cape Breton Island.

Highlights of exploration and development activity for gold during the year centred on advanced exploration projects at the Tangier, Caribou, Moose River and Mooseland gold properties in Halifax County, the Forest Hill and Upper Seal Harbour gold properties in Guysborough County and the McMillan Flowage area of northern Cape Breton Island (Table 4).

Coxheath Gold Holdings Limited continued underground exploration and development work on the Tangier gold property in Halifax County during the first half of 1989. Additional drifting and raising, analytical work and underground diamond-drilling were completed as part of an ongoing program to evaluate ore reserves. The company received a mining lease for the property in December 1988 and went into production at the beginning of 1989 for a short time before suspending operations due to a lack of operating capital.

Antioch Resources (N.S.) Limited began a detailed underground exploration program on the Caribou, Halifax County, gold property at the beginning of 1989. The company acquired the property in December 1988 following a decision by Seabright Explorations Incorporated to drop its

Table 2. *Major companies involved in recent mineral exploration in Nova Scotia.*

	1987	1988	1989	Nova Scotia Office Location, 1989
BP Resources Canada Limited	x	x	-	
Canamax Resources Incorporated	-	-	-	
Conwest Exploration Company Limited	-	-	-	
Dominion Explorers Incorporated	x	-	-	
Domtar Incorporated	x	x		Windsor
Eldorado Resources Limited (ground alienation, U moratorium)	-	-	-	
Esso Resources Ltd.	-	-	x	
Falconbridge Limited	x	x	x	Windsor
Fundy Gypsum Company Limited	x	x	x	Windsor
Georgia Pacific Corporation	-	x	x	Sugar Camp
Granges Exploration Limited	x	x	x	Halifax
Hecla Mining Company of Canada Limited	-	x	x	Mooseland
Husky Oil Operations Limited (through Scominex*)	x	x	x	
Inco Exploration and Technical Services Inc. (manager of Scominex*)	x	x	x	Halifax
Interuranium Canada Limited (ground alienation, U moratorium)	-	-	-	
Lafarge Canada Incorporated	x	x	x	Brookfield
Mosher Limestone Limited	-	-	-	Upper Musquodoboit
National Gypsum (Canada) Limited	x	x	x	Milford Station
Noranda Exploration Company Limited	x	x	x	
Nova Construction Company	-	-	x	Antigonish
Nova Scotia Resources Ltd. (through Scominex*)	x	x	x	
Nova Scotia Sand and Gravel Limited (division of L. E. Shaw Limited)	x	x	x	Lantz
Placer Development Limited	x	-	-	
Republic Gypsum Company	-	-	-	
Rio Algom Limited	-	-	x	
Scotia Limestone Limited	x	x	x	Sydney
Teck Explorations Limited	x	-	-	
Timminco Limited (Chromasco)	-	-	-	
Westminer Canada Limited		x	x	
Westray Coal Incorporated		x	x	

x indicates work performed
- company inactive
* Scotian Mineral Exploration Venture

option on the property after completing an extensive underground evaluation at the Holman mine. Underground diamond-drilling and bulk sampling were completed during the year to assist in the evaluation of mineable ore reserves and exploration potential of the property.

Orex Exploration Incorporated, in an option/purchase agreement with Onitap Resources Incorporated, continued a detailed exploration program on the Upper Seal Harbour gold property near Goldboro, consisting of additional surface diamond-drilling and detailed drill core analysis. An agreement was reached with Onitap in 1989 that will allow Orex to acquire full ownership of the property. A feasibility study was also completed mid-year outlining the first phase of an underground mining operation on the property.

Seabright Explorations Incorporated, under the direction of Westminer Canada Limited, continued a large-scale surface bulk sampling program on the Moose River gold property (Touquoy zone) to test a large tonnage, low grade, argillite-hosted zone outlined in recent drilling. Westminer Canada Limited (Seabright division) also continued a detailed evaluation of the Forest Hill gold property which included additional underground bulk sampling at the Teasdale Mine. The company phased out operations at Forest Hill at the end of September 1989.

Table 3. Junior and private exploration companies involved in recent mineral exploration in Nova Scotia.

	1987	1988	1989	Nova Scotia Office Location, 1989
Acadia Mineral Ventures Limited	x	x	x	Truro
Antioch Resources (N.S.) Limited		-	x	
Aquagold Resources Incorporated (formerly Torene Gold Exploration Limited)	x	x	x	Dartmouth
Arisaig Explorations Limited	x	x	x	
Atlantic Goldfields Incorporated	x	x	-	
Aurion Minerals Limited	x	x	x	Halifax
Aurtec Mining Development Limited		x	x	
Belore Mines Limited		x	-	
Benrock Limited		-	x	Antigonish
Biron Bay Resources Limited		x	x	
Bluestack Resources Limited	x	-	-	
Breakwater Resources Limited (formerly Novamin Resources Incorporated)	x	x		
Carbontec Industries Limited	x	x	x	Halifax
Carrick Gold Resources Limited	x	x	x	Dartmouth
Cobequid Resources Limited	x	x	-	Halifax
Coxheath Gold Holdings Limited	x	x	x	Bedford
Deak Resources Corporation (formerly Wilco Mining Company Limited)	x	x	x	
Dynamic Consolidated Resources Limited		x	-	
Exploration Orex Inc.		x	x	Goldboro
Fenorex Mineral Investigations Limited	x	x	x	Sydney River
Four Seasons Resources Limited	x	-	-	
Gedoro Mining Limited	x	-	-	Halifax
Gold Bank Resources Limited		-	x	
Gold Brook Developments Limited	x	x	x	Margaree
Gordex Minerals Limited	x	x	-	
Greenstrike Gold Corporation	x	x	-	
Gunnar Gold Incorporated		x	-	
Gusto Resources Limited	x	x	x	Halifax
Hathor Resources Limited	-	x	-	
Jascan Resources Incorporated	x	x	-	Halifax
Kelrock Limited	x	x	x	Dartmouth
Little Lake Gold Mines Limited	-	x	x	Dartmouth
Lodestone Limited	x	x	x	Halifax
Lodge Resources Incorporated	x	-	-	
Lotus Resources Limited	-	x	x	Dartmouth
Macree Resources Incorporated		-	x	Dartmouth
Magstone Development Limited	x	-	-	
Mer Resources Incorporated	x	-	-	
MEX Explorations Limited	x	x	-	Truro
Midas Minerals Incorporated	-	x	-	
Mill City Gold Incorporated		x	-	
Murray Brook Resources Inc. (formerly Northumberland Mines Ltd.)	x	x	-	
NovaGold Resources Incorporated	x	x	x	Halifax
Oldham Resources Limited	x	x	-	Dartmouth
Onitap Resources Incorporated	x	x	x	
Orevco Incorporated		x	-	
Orleans Resources Incorporated		x	-	
Pan East Resources Incorporated	x	x	-	
Petromet Resources Limited	x	x	-	
Scotia Prime Resources Limited	x	x	x	Halifax
Seabright Resources Incorporated	x	x	x	Sackville
Seascope Consultants Limited	x	x	-	Halifax
Skyerock Minerals Limited	x	x	x	Antigonish
Sunrise Metals Corporation		x	-	
The Potter Mine (Nova Scotia) Limited	x	x	x	
Tri-Explorations Limited	x	x	x	Dartmouth
Tusk Minerals Limited		x	-	
United Reef Petroleums Limited		x	-	
W. Bruce Dunlop Limited	x	x	-	
Web Exploration Services Limited	x	-	-	

x indicates work performed

- inactive

Table 4. Principal exploration and development programs, 1989.

COMPANY/LOCATION	COMMODITY	PROGRAM COMPLETED	CURRENT STATUS
Acadia Mineral Ventures Limited			
Cochrane Hill, Guysborough County	Gold	Diamond-drilling continued from 1988 program	Project terminated
East Kemptville, Yarmouth County	Tin	Diamond-drilling	Not known
Fanning Lake, Yarmouth County	Gold	Diamond-drilling	Not known
Antioch Resources (N.S.) Limited Caribou, Halifax County	Gold	Underground bulk sampling, test mining, metallurgical studies, diamond-drilling	Ongoing
AquaGold Resources Incorporated Glen Morrison, Cape Breton County	Limestone	Diamond-drilling, bulk sampling	On hold
Aurtec Mining Development Limited Cranberry Head, Yarmouth County	Gold	Diamond-drilling	Drilling completed in early 1990
Carrick Gold Resources Limited Montague, Halifax County	Gold	Geological mapping, trenching, diamond-drilling	Additional drilling planned for 1990
Coxheath Gold Holdings Limited Tangier, Halifax County	Gold	Underground drifting and raising, analytical work and diamond-drilling	On hold
Denk Resources Corporation Stirling, Cape Breton County	Base metals	Diamond-drilling continued from 1988 program	Airborne geophysical survey completed during January 1990
Esso Resources Canada Limited Springhill, Cumberland County	Coal	Seismic survey, diamond- drilling, rotary drilling	On hold
Falconbridge Limited			
Kempt Snare Lake, Yarmouth County	Tin	Diamond-drilling	Not known
Little Narrows, Victoria County	Base metals	Diamond-drilling	Additional drilling planned for 1990
Stirling area, Cape Breton County	Base metals	Mapping, silt and rock sampling, airborne geophysical survey	Additional work planned for 1990
Georgia Pacific Corporation			
Big Brook, Inverness County	Gypsum	Diamond-drilling	Not known
Sugar Camp, Inverness County	Gypsum	Diamond-drilling	Not known
Granges Exploration Limited Solomon Lake, Yarmouth County	Tin	Diamond-drilling	Project terminated
Hecla Mining Company of Canada Ltd. Mooseland, Halifax County	Gold	Completed construction of a 125 m shaft	Project terminated
Inco Gold Management Incorporated Cape Breton Highlands, Inverness and Victoria Counties	Base metals	Geological mapping, prospecting, trenching	Additional work planned for 1990
Kelly Rock Limited Englishtown, Victoria County	Aggregates	Diamond-drilling	Not known
Lafarge Canada Incorporated South Maitland, Hants County	Limestone	Surface bulk sampling	On hold
National Gypsum (Canada) Limited Dutch Settlement, Halifax County	Gypsum	Diamond-drilling	Not known
Noranda Exploration Company Limited Rocky Brook, Inverness County	Gold	Diamond-drilling, trenching	Not known
Creignish Hills, Inverness County	Gold	Prospecting, rock and silt sampling	Additional work was recommended
Nova Scotia Gypsum Company Limited Dutch Settlement, Halifax County	Gypsum	Pre-production studies	Ongoing
Orex Exploration Incorporated Upper Seal Harbour, Guysborough County	Gold	Mining feasibility studies, detailed drill core analysis	Underground diamond- drilling started January 1990
Outland Resources Corporation Cheticamp, Inverness County	Gold	Prospecting, soil sampling, trenching	Additional work was recommended
Pioneer Coal Company Limited Westville, Pictou County	Coal	Diamond-drilling	Not known
Ridge Brokers Limited			
Southside Antigonish Harbour, Antigonish County	Limestone	Diamond-drilling	Not known
Ohio River, Antigonish County	Limestone	Diamond-drilling	Not known
Rio Algom Exploration Incorporated East Kemptville, Yarmouth County	Tin	Diamond-drilling	Not known
Seabright Explorations Incorporated Moose River, Halifax County	Gold	Geological mapping, ground geophysical surveys, diamond- drilling	On hold
Westminer Canada Limited			
Beaver Dam, Halifax County	Gold	Underground bulk sampling	Project terminated
Forest Hill, Guysborough County	Gold	Underground bulk sampling	Project terminated
Gays River Pb-Zn mine, Halifax County	Base metals	Dewater old workings, underground bulk sampling	Not known
Gays River area, Halifax County	Base metals	Diamond-drilling	Not known
Westray Coal Incorporated Plymouth, Pictou County	Coal	Construction of access tunnels	Work to resume in early 1990

Hecla Mining Canada Limited, in a joint venture agreement with Biron Bay Resources Limited, completed the construction of a 125 m shaft on the 'West' zone of the Mooseland gold property early in 1989. Work on the property was suspended mid-year when Biron Bay was unable to continue financing the project.

Inco Gold Management Incorporated continued a large-scale surface exploration program in the McMillan Flowage area consisting of detailed geological mapping and extensive trenching. The company is completing a detailed assessment of a number of gold anomalies outlined in a regional program started in the area in 1986.

Base Metals

Exploration activity for base metals demonstrated a modest increase in 1988 and this trend continued in 1989, reflecting the shift away from precious metals, particularly by the major companies. Several exploration programs were undertaken throughout the Province in a variety of geological environments. Both reconnaissance surveys and follow-up work on known occurrences were carried out (Table 4).

Westminer Canada Limited (Seabright division) continued a detailed evaluation of the former lead-zinc producer at Gays River, Halifax County, including dewatering the old workings and completing underground bulk sample tests. The deposit is hosted by lower Mississippian carbonates of the Windsor Group with a reserve estimate of 1.1 million tonnes grading 5% Pb and 9.4% Zn.

Falconbridge Limited completed a preliminary drilling program to evaluate the Jubilee lead-zinc property in Victoria County. The mineralization is hosted by Windsor Group rocks, with a reserve estimate of 0.5 million tonnes grading 6% combined Pb-Zn.

Rio Algom Exploration Incorporated carried out exploration drilling for tin in the vicinity of the company's East Kemptville, Yarmouth County, tin deposit during 1989. The deposit occurs in a 'specialized' granite along the contact between the Davis Lake Pluton and overlying quartzites of the Goldenville Formation. Exploration for base metals was also carried out in the East Kemptville area by Falconbridge Limited and Acadia Mineral Ventures Limited.

Industrial Minerals

The production of industrial minerals in Nova Scotia represents an important and growing segment of the mining industry in the Province and accounts for roughly 45% of the total value of minerals currently produced. These commodities are mined throughout the Province and include both non-metallic commodities (gypsum, salt, silica, peat, barite) and construction materials (clay, shale, limestone, aggregates). Exploration for industrial minerals has demonstrated a modest but steady increase in recent years, reflecting the growth in the industry, and is highlighted by efforts to expand on current reserves as well as locate new deposits (Table 4).

Georgia Pacific Corporation continued development drilling on the Sugar Camp gypsum deposit near Port Hawkesbury. The company also completed exploration drilling in the Sugar Camp area as well as in the vicinity of their gypsum quarry at Big Brook. National Gypsum (Canada) Limited completed exploration drilling for gypsum at Dutch Settlement, Halifax County.

Nova Scotia Gypsum Company, a division of Fundy Gypsum Company Limited, completed pre-production studies at the company's proposed new gypsum quarry at Dutch Settlement, Halifax County.

Lafarge Canada Incorporated continued to evaluate potential limestone deposits in the vicinity of its quarry operations near Brookfield, Colchester County. AquaGold Resources Incorporated completed a diamond-drilling program and bulk sampling on the Glen Morrison limestone deposit near Sydney, Cape Breton County.

The development of a new aggregate operation was continued during 1989 by Kelly Rock Limited near Englishtown, Victoria County, and included diamond-drilling and bulk sample testing.

Coal

Exploration for coal in 1989 continued at roughly the same level of activity as in recent years. Work was directed toward developing additional reserves on currently producing properties as well as developing new reserves in other coal basins (Table 4).

Nova Construction Company Limited completed an exploration drilling program for coal near Westville, Pictou County, during 1989. The company operates a small strip mining operation at

Westville (Pioneer Coal Company Limited). Esso Resources Canada Limited also carried out geophysical surveys and exploration drilling for coal near Springhill, Cumberland County.

A major development project was undertaken by Westray Coal Incorporated to begin the construction of a new underground thermal coal mine at Plymouth, Pictou County. Work was started early in the year with the preparation of surface facilities and the construction of two parallel ramps to access the coal reserves.

DRILL CORE LIBRARIES[1]

J. D. Langille

The four Nova Scotia Department of Mines and Energy (NSDME) drill core libraries and sample storage facilities are maintained by the Resource Geology Section of the Mineral Development Division. Two permanent staff members, J. Langille and D. Murphy, are core library supervisor and transportation officer, respectively. Three term staff members, geologists W. Palmer and D. Weir and mineral technician J. O'Leary, are employed under an extension of the Canada - Nova Scotia Mineral Development Agreement.

Two of the four core facilities (Fig. 1) are located at Stellarton, Pictou County (one at the NSDME regional office on Bridge Avenue and one in the Stellarton Industrial Park on Acheron Court), the third is located on Dakota Drive in the Debert Air Industrial Park, Colchester County, and the fourth is located near Malagawatch, Inverness County. Only the Stellarton locations are staffed daily.

The main, and largest, facility is at the Acheron Court locality in Stellarton where four arch-rib buildings provide 32,000 square feet of storage and examination area. Diamond-drill core is stored in stacks on wooden pallets in unheated storage areas and moved by a propane-powered forklift truck to and from two heated examination areas. Office space is provided for core library staff on the second floor above the examination area in the newest building (opened in 1988).

Core at the regional office on Bridge Avenue in Stellarton is stored on an inside rack and in covered racks attached to the rear of the building. Core at Debert and Malagawatch is also stored on racks.

Debert serves as the main rock storage facility, using a system of plastic tubs on pallets. The regional office in Stellarton also has wooden cabinets with trays where vials of oil well cuttings, rock thin section slabs, sieved soil and stream sediment fractions, ground rock powders and other prepared samples are stored.

Most core is not kept on a confidential basis and can be viewed by any visitor. Sampling of most unsplit core is permitted while sampling of previously split core is only permitted under special conditions. All pulps and sample rejects and all analytical results must be returned to the core library to reduce unnecessary repeated sampling in the future. The Stellarton facilities are provided with diamond saws, core splitters, a binocular microscope, an ultraviolet lamp, a scintillometer and various other laboratory equipment. The other storage facilities can be provided with this equipment on special notice.

Use of the core library facilities declined slightly in 1989. This decline is viewed as a reflection of the downturn in the mineral exploration industry in general and the decline in gold exploration in particular. A total of 159 users (81 staff and 78 non-staff) spent 502 person days at the main Stellarton locations. Core from 264 diamond-drill holes was examined and 830 samples were selected for additional work.

At the end of 1989 the core libraries held approximately 487 680 m of core. During 1989 another 16 662 m were added (Table 1). Government accounted for 17.5% of the drilling projects (35 drillholes) and 23.2% (3862 m) of the core. Industry accounted for 82.5% of the drilling projects (165 drillholes) and 76.8% (12 800 m) of the core.

MINERAL DEVELOPMENT AGREEMENT PROGRAM

Nova Scotia Department of Mines and Energy core library geologist W. Palmer continued to examine and evaluate diamond-drill core from areas of the Province where substantial drilling has taken place and large amounts of core have been generated.

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[1] Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

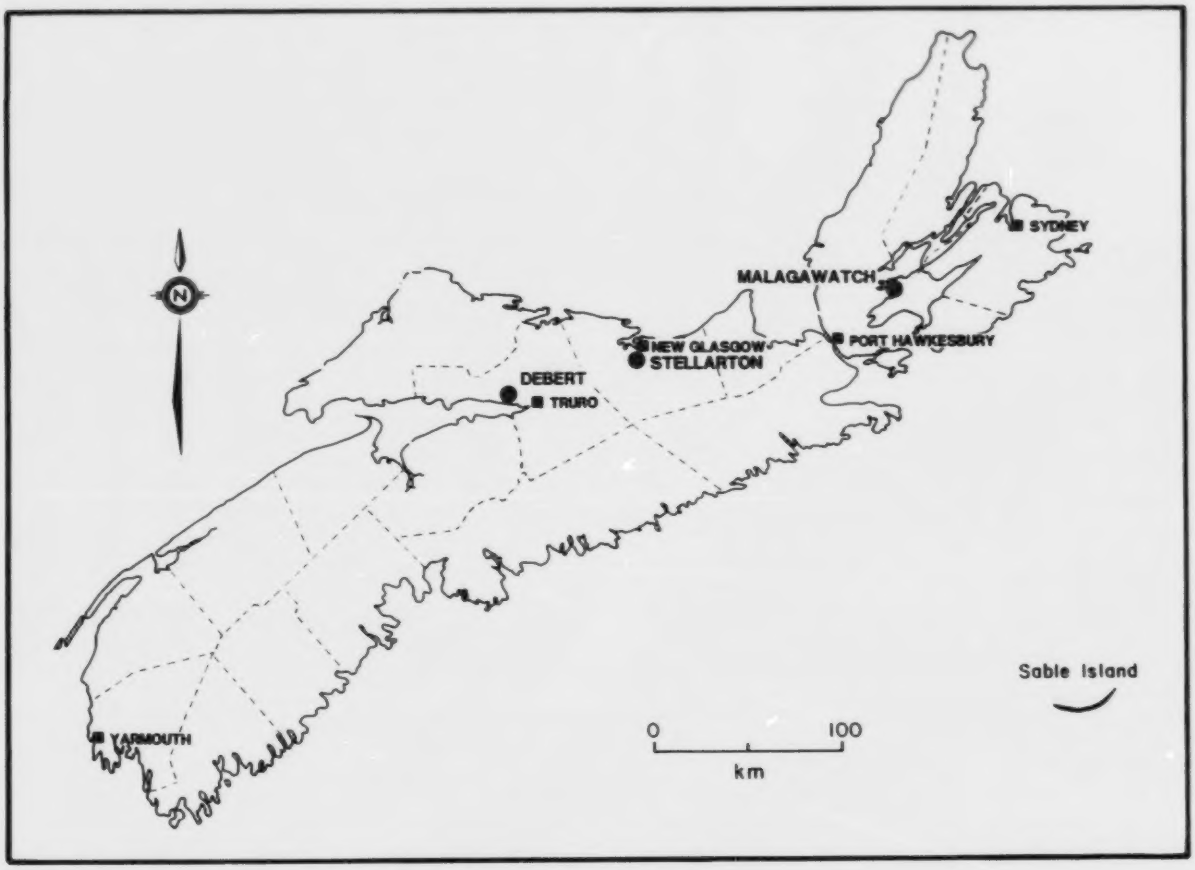

Figure 1. Location of drill core libraries and sample storage facilities in Nova Scotia.

These evaluations will permit the eventual disposal of surplus core and allow additional packages of core to be received and processed. No large-scale disposal of core has taken place to date. Recommendations for disposal of up to 60% of several packages have been put forward for departmental review. No core will be taken out of the core libraries' holdings or disposed of until interested parties are informed.

During 1989 work proceeded on tabulation of drillhole statistics and report preparation on the Getty Mines, Gays River lead-zinc deposit, Colchester County; the Walton barite - base metal deposit, Hants County; the Meaghers Grant area, Halifax County; and the Lake Enon celestite (celestine) deposits, Cape Breton County. A large package of core, 6956 m, from the Silver Mine/Yava lead deposit area, Cape Breton County, was received during the year. This core is being processed and integrated with core previously received from this area.

D. Weir, project geologist, transferred from the Mineral Resources Division to the Mineral Development Division. He is currently working on smaller packages of core that have never been fully evaluated for their suitability of retention. This work will also see some core being classified as surplus.

J. O'Leary, mineral technician, assists the project geologists and gives help to other core library users as required.

For further information on core library facilities or to request services, telephone core library supervisor Jim Langille (902) 752-4842 or regional geologist John McMullin (902) 752-8429.

Table 1. Core library additions in 1989.

COMPANY OR GROUP	LOCATION OF DRILLING	YEAR OF DRILLING	NO. OF HOLES	TOTAL METRES
AquaGold Resources Inc.	Glen Morrison, Cape Breton County	1989	11	272
Granges Exploration Ltd.	East Kemptville, Yarmouth County	1989	1	120
Inmin Resources/ Pioneer Coal	Brierly Brook, Antigonish County	1986	15	285
NSDME Mineral Resources Division	Big Indian Lake, Hants County	1989	3	771
NSDME Mineral Resources Division	Eureka/Island East River, Pictou County	1989	1	633
NSDME Mineral Development Division	Nictaux, Annapolis County	1989	3	140
NSDME Energy Resources Division	Offshore Cape Breton Coal Core	1977/78	19	1 656
NSDME Mineral Development Division	Sawmill Brook, Pictou County	1986	1	13
NSDME Energy Resources Division	South Athol, Cumberland County	1989	1	366
NSDME Mineral Development Division	South River Lake, Antigonish County	1989	1	54
NSDME Mineral Development Division	South Williamston, Annapolis County	1989	3	56
NSDME Mining Engineering Division	Stellarton, Pictou County	1989	3	173
Phelps Dodge	Silver Mine, Cape Breton County	1962-64 1973/74	90	6 056
Pioneer Coal	Sydney Airport, Cape Breton County	1986	5	51
Pioneer Coal	Westville, Pictou County	1986	8	88
Pioneer Coal	Westville, Pictou County	1989	10	464
Ridge Brokers Limited	Ohio, Antigonish County	1989	4	133
Ridge Brokers Limited	Southside Antigonish Harbour, Antigonish County	1989	8	189
Suncor Inc.	Pictou Coal Basin, Pictou County	1985/86	13	5 142
TOTALS			200	16 662
Government			35	3 862
Industry			165	12 800

THE SOUTHWEST NOVA SCOTIA TIN DOMAIN, YARMOUTH COUNTY, NOVA SCOTIA: IMPLICATIONS FOR TIN METALLOGENY IN THE MEGUMA TERRANE, NOVA SCOTIA[1]

D. J. Kontak, G. A. O'Reilly and A. K. Chatterjee

INTRODUCTION

The East Kemptville Sn-Zn-Cu-Ag deposit (56 million tonnes, 0.165% Sn; Moyle, 1985), located in Yarmouth County of southern Nova Scotia, represents the only primary producer of tin (1988 production 3791 tonnes) in North America and, therefore, assumes prominent status both with respect to its importance as a supplier of this strategic metal and its metallogenic uniqueness. In addition, the proximity of other significant granite-related mineralized centres in Atlantic Canada (e.g. Mount Pleasant Sn-W-Mo-Bi, Burnt Hill W and Lake George Sb(-W) deposits, New Brunswick; Grey River W and Ackley Granite Mo-W-Sn mineralization, Newfoundland) magnifies the regional metallogenic significance and potential of granitoid rocks in the Canadian Appalachians.

Recent work by personnel of the Nova Scotia Department of Mines and Energy on the East Kemptville deposit and surrounding environment has provided insight into the regional and local geology of the southwest Nova Scotia tin - base metal - precious metal domain. There is an abundance of known mineralization within this area (Fig. 1) which we interpret to reflect the enormous potential of the region for additional discoveries. In this paper the salient aspects of the geological setting and mineral deposit characteristics of this region are reviewed and a working model is presented to accommodate the data compiled to date.

REGIONAL GEOLOGICAL SETTING

The area of interest is located within the Meguma Terrane of southern Nova Scotia, the easternmost terrane of the Appalachian collage. The geology of the Meguma Terrane is dominated by Lower Paleozoic Meguma Group metaturbiditic sedimentary rocks and Late Devonian metaluminous to peraluminous granitoid rocks, the most prominent being those of the ca. 370 Ma old South Mountain Batholith. The recent discovery of high-grade amphibolite and granulite facies gneiss occurring as a gneiss dome (emplacement age of ca. 370 Ma) in the Liscomb area of southern Nova Scotia (Giles and Chatterjee, 1986; Kontak *et al*., 1990a) and as xenoliths in ca. 370 Ma old mafic dyke rocks (Kemptster *et al*., 1989; Ebertz *et al*., 1989) outcropping along the Atlantic coast indicates that the Meguma Group is structurally underlain by a package of metasedimentary and metavolcanic rocks.

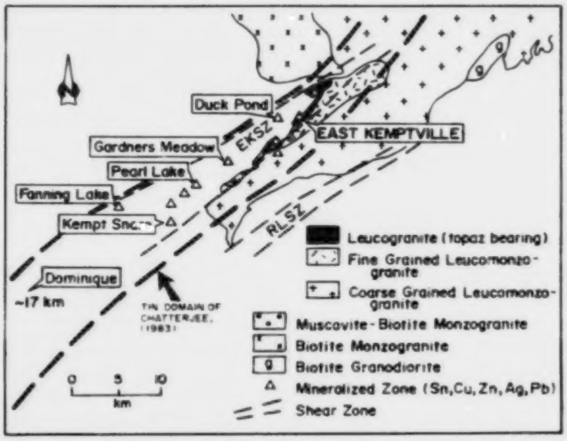
Duck Pond
Gardners Meadow
Pearl Lake
Fanning Lake
Kempt Snare
Dominique
~17 km
EKSZ
EAST KEMPTVILLE
RLSZ
TIN DOMAIN OF CHATTERJEE, (1983)
0 5 10
km
Leucogranite (topaz bearing)
Fine Grained Leucomonzo-granite
Coarse Grained Leucomonzo-granite
Muscovite-Biotite Monzogranite
Biotite Monzogranite
Biotite Granodiorite
Mineralized Zone (Sn,Cu,Zn,Ag,Pb)
Shear Zone

Figure 1. Geological setting of the southwest Nova Scotia tin domain showing the subdivisions of the western part of the South Mountain Batholith, outline of the Rushmere Lake (RLSZ) and East Kemptville (EKSZ) shear zones, outline of Chatterjee's (1983) tin domain, and locations of tin, base metal and precious metal mineralization. Note the pronounced linearity of the leucogranite bodies, which subparallel the shear zone boundaries.

The Meguma Terrane was regionally deformed and metamorphosed during the Acadian Orogeny

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[1] Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

of middle to late Devonian time, probably a result of its collision and emplacement alongside the North American continent (Keppie, 1982, 1989). Younger, less pervasive deformational events are recognized within the Meguma Group as northeast-trending, predominantly ductile (±brittle) shear zones and as both brittle and ductile deformation zones within the large South Mountain Batholith (Horne *et al.*, 1988; R. J. Horne, personal communication, 1989). The presence of similar and in some cases potentially continuous structures in overlying Carboniferous rocks reflects the continued transpression of the Meguma Terrane well after its initial docking with North America.

The metallogeny of the Meguma Terrane is dominated by auriferous quartz veins within the Meguma Group and Sn-W-U-base metal mineralization within the ca. 370 Ma old peraluminous granites (Chatterjee, 1983). The most prominent granite-related mineralization, occurring within the South Mountain Batholith, is represented by the Millet Brook U deposit (similar in many respects to the vein type and episyenite uranium deposits of the Massif Central, France) and the East Kemptville Sn-Zn-Cu(-Ag) deposit, but the presence of numerous occurrences of similar mineralization indicates a high potential for other deposits.

GEOLOGICAL SETTING OF THE SOUTHWEST NOVA SCOTIA TIN DOMAIN

The salient aspects of the geology of the southwest Nova Scotia tin domain, first recognized by Chatterjee (1983), are summarized in Figure 1. The most important features illustrated by this diagram are: (1) the presence of numerous sites of tin and associated base metal and precious metal mineralization, (2) the coincidence of the mineralized zones with an areally extensive shear zone (East Kemptville Shear Zone), and (3) the presence of highly evolved felsic intrusions along the western margin of the South Mountain Batholith. A limited amount of drilling has delineated a greisenized cupola underlying the Kempt Snare Lake mineralized zone (approximately 4-5 km west of the South Mountain Batholith) and we infer that a similar situation exists for the remaining deposits (e.g. Duck Pond, Pearl Lake, Gardners Meadow, Dominique).

The western part of the South Mountain Batholith is referred to as the Davis Lake Pluton (MacDonald *et al.*, 1989). Only part of this pluton is shown in Figure 1. The pluton, which intrudes Meguma Group metasedimentary rocks, is composite in nature with granodiorite, biotite monzogranite, muscovite-biotite monzogranite, leucomonzogranite and topaz-bearing leucogranite phases present. The more evolved phases are characterized by the presence of variably developed deuteric alteration ± mineralization. All the granitic phases contain variably developed planar fabrics including mylonites, C-S fabrics, aligned K-feldspar megacrysts and micas, and recrystallized quartz grains.

The age of the Davis Lake Pluton is ca. 370 Ma, based on ^{40}Ar/^{39}Ar (Reynolds *et al.*, 1981; J. D. Keppie, personal communication, 1989) and Pb-Pb isotopic analyses (our unpublished data). Hence, the Davis Lake Pluton is temporally equivalent to the rest of the South Mountain Batholith. Younger radiometric ages obtained on samples from the Davis Lake Pluton (e.g. Richardson *et al.*, 1989; Reynolds *et al.*, 1981) record effects of overprinting tectono-thermal events.

The East Kemptville Shear Zone is a northeast-trending, approximately 1-4 km wide zone of heterogeneously developed, intense, ductile (± brittle) deformation which transects both the Meguma Group and granitoids of the South Mountain Batholith. The fact that the shear zone parallels the northwest contact of the batholith suggests that it may represent a reactivated structure that was prominent during intrusion of the batholith. A combination of Rb/Sr and ^{40}Ar/^{39}Ar geochronology (Zentilli and Reynolds, 1985; Kontak *et al.*, 1989, 1990b; Soehl *et al.*, 1989) indicates a minimum age of ca. 340 Ma for movement and further indicates that the shear zone likely remained active well into the Permian (250 Ma ago).

Mineralization within the tin domain consists of both granite- and metasediment-hosted types. The former is typified by the East Kemptville deposit, while the latter is best represented by the Duck Pond and Dominique deposits. In the following section the prominent aspects of some of the mineralized centres are presented.

MINERALIZED CENTRES

Duck Pond Deposit (Sn, Cu, Zn)

The Duck Pond deposit, located approximately 2 km west of the East Kemptville deposit (Fig. 1), is hosted by strongly deformed, greenschist facies, argillaceous and siliceous sediments of the Goldenville-Halifax transition zone, stratigraphically part of the Cambro-Ordovician Meguma Group. The transition zone is characterized by finely laminated manganiferous beds, locally rich in calcareous or calc-silicate nodules and sulphides, with elevated values of Ba, Pb, Zn, Cu, Mo, W and Au compared to average Meguma Group lithologies (Graves and Zentilli, 1988). Exploration activity by Shell Canada Resources Ltd. (Kohlsmith and Wilson, 1980) consisted of till geochemistry, induced-polarization surveys and 26 diamond-drill holes (total 791 m). More recently, Pitre and Richardson (1989) completed a detailed mineralogical and petrographical study of the mineralization, Hattie (1989) mapped the deposit area and representative drill core in detail and O'Reilly (unpublished data) analyzed whole-rock samples and obtained electron microprobe data on garnet and chlorite. The following is a synthesis of work from these sources.

The deposit area (1.5 km by 1.2 km; Fig. 2) is underlain by northeasterly-trending units composed of alternating argillite, siliceous argillite and quartzite. The northern extremity of the deposit area is underlain by intensely hematized argillite. The argillaceous units contain a penetrative, northeast-trending fabric (avg. 062°/subvertical) and in some places this is overprinted by a shear fabric of similar orientation. A late, flat-lying cleavage with dextral offset is locally observed.

Based on diamond-drilling, three subparallel zones of vein- and stratabound-type mineralization (A, B and C zones) have been delineated (Fig. 2). The mineralized zones are subparallel to lithological contacts and at least one of these (A zone) is coincident with a zone of intense shearing. Tin mineralization occurs in three contrasting styles: (1) stratabound type, which is coincident with hydrothermally altered quartzitic sediments characterized by the assemblage chloritoid, pseudothuringitic chlorite, a compositionally unusual hydrothermal garnet containing equal proportions of spessartine-almandine-grossular, and cassiterite; (2) quartz-chlorite-cassiterite-sulphide (pyrite, sphalerite, chalcopyrite) veins; and (3) silicified and sericitized zones containing pyrite ± cassiterite ± base metals. A stage of pervasive hematitic alteration is superimposed on all previous mineralization and in some areas very soft, fissile argillite may contain clay alteration, but this remains to be confirmed.

Pitre and Richardson (1989) classify the mineralization according to alteration type (i.e. alkalic, chloritic and argillic) with tin mineralization occurring in the chloritic alteration stage. Base metal (Cu, Zn) mineralization in part overlaps and post-dates cassiterite (i.e. associated with argillic alteration). We note, however, that in our studies no anorthoclase (Pitre and Richardson's (1989) index mineral for alkalic alteration) has been observed and that the absence of any clay minerals (see Table 2 in Pitre and Richardson, 1989) raises the question of why they have used the term argillic alteration (cf. Bates and Jackson, 1980).

Results of a lithogeochemical study (82 samples) for 17 elements (Mn, Fe, F, Ag, As, Au, B, Cd, Co, In, Cu, Li, Pb, Rb, Sb, Sn, Zn) are summarized in Figure 3 and discussed below. Compared to the geochemical database for the Goldenville-Halifax transition zone (Graves and Zentilli, 1988) the Duck Pond samples are notably enriched in Rb and Zn with broadly similar abundances for other elements (e.g. Cu, Pb, As). However, compared to average Meguma Group sedimentary rocks the following is noted for the Duck Pond sediments: (1) enrichment in Mn (0.2-0.5 wt. % MnO) compared to typical rocks of the Meguma Group; (2) concentrations for many of the trace elements comparable to concentrations in unmineralized Meguma Group lithologies (Fig. 3) with slight enrichment in As, Cu, Zn, Pb, Rb and F in some samples; (3) the lack of enrichment in B and the comparatively minor enrichment in F; and (4) the considerable enrichment of the samples in Sn (Fig. 4) compared to average values for the Meguma Group (2-5 ppm), almost to the mutual exclusion of other elements (e.g. W, Zn, Cu, Ag).

Electron microprobe analyses of chlorite and garnet are summarized in Figure 5. The chlorite is of ripidolitic to pseudothuringitic composition with enrichment in both Fe and Mn compared to chlorites from unmineralized rocks outside of the Duck Pond deposit (i.e. regional chlorite). In addition, the chlorites are markedly different in composition from those found in Meguma Group hosted gold deposits (Fig. 5) with respect to their enrichment in both Fe and Mn. Garnet in vein and wall rock lithologies has a restricted composition with an overall dominance of Fe, Ca and Mn end members (>95 mole% combined). Compositionally this garnet differs from regional metamorphic garnet, including those found in Mn-rich lithologies and coticules (fields F and G in Fig. 5c), and hydrothermal garnet from Meguma gold deposits (Fig. 5c). Core-rim profiles for garnets (Fig. 5d) indicate normal and reverse zoning with respect to Ca and Mn which is interpreted to reflect transient

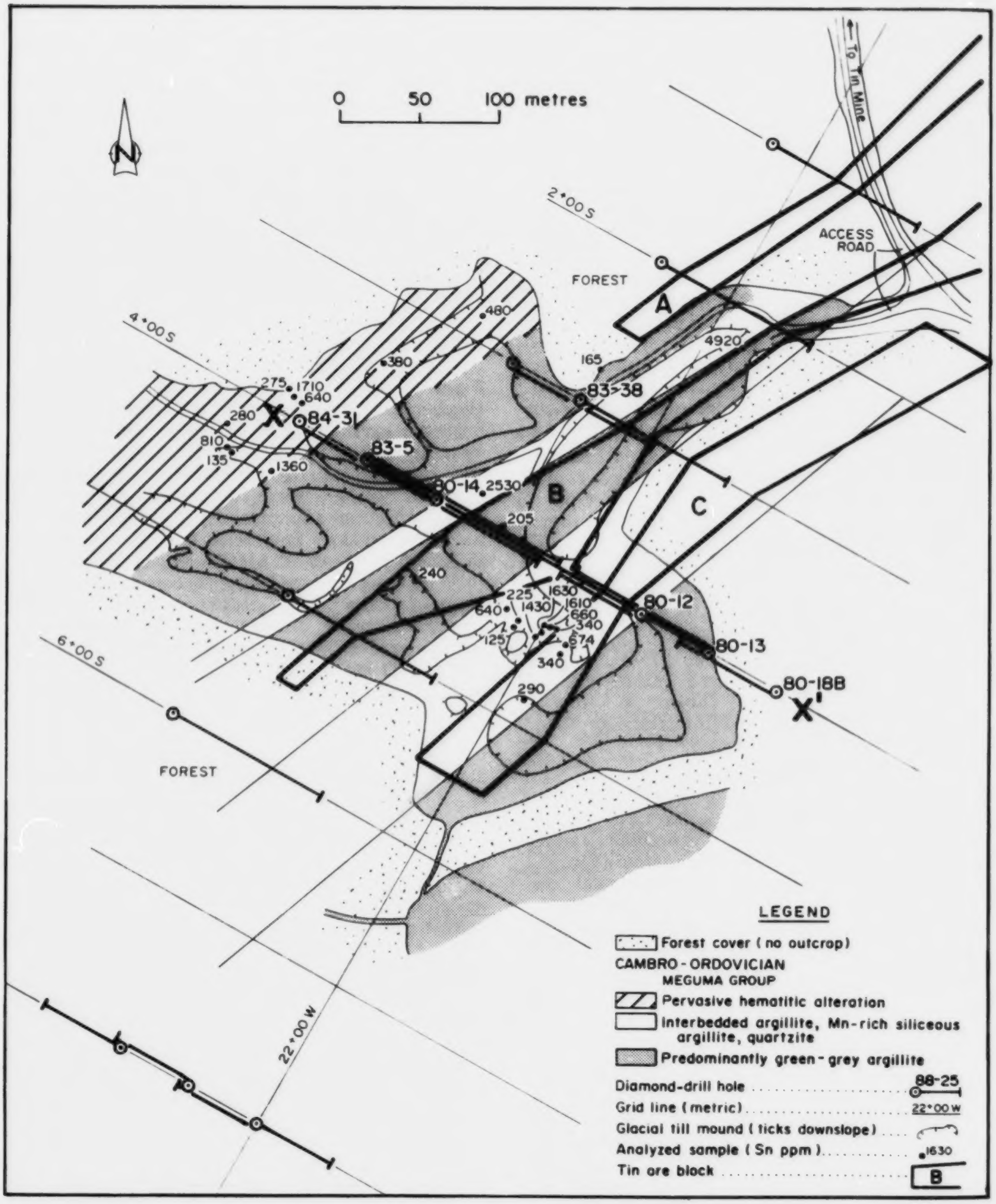
0 50 100 metres
N
To Tin Mine
2+00 S
ACCESS ROAD
FOREST
A
4920
165
83-38
480
380
4+00 S
275
1710
640
280
X
84-31
810
135
1360
83-5
80-14
2530
B
C
205
240
225
1630
1610
640
1430
660
340
125
574
340
80-12
80-13
80-18B
X'
290
6+00 S
FOREST
22+00 W
LEGEND
Forest cover (no outcrop)
CAMBRO-ORDOVICIAN
MEGUMA GROUP
Pervasive hematitic alteration
Interbedded argillite, Mn-rich siliceous argillite, quartzite
Predominantly green-grey argillite
Diamond-drill hole
88-25
Grid line (metric)
22+00 W
Glacial till mound (ticks downslope)
Analyzed sample (Sn ppm)
1630
Tin ore block
B

Figure 2. Geological map of the Duck Pond Zone showing the trend of the three main zones of mineralization as projected to surface.

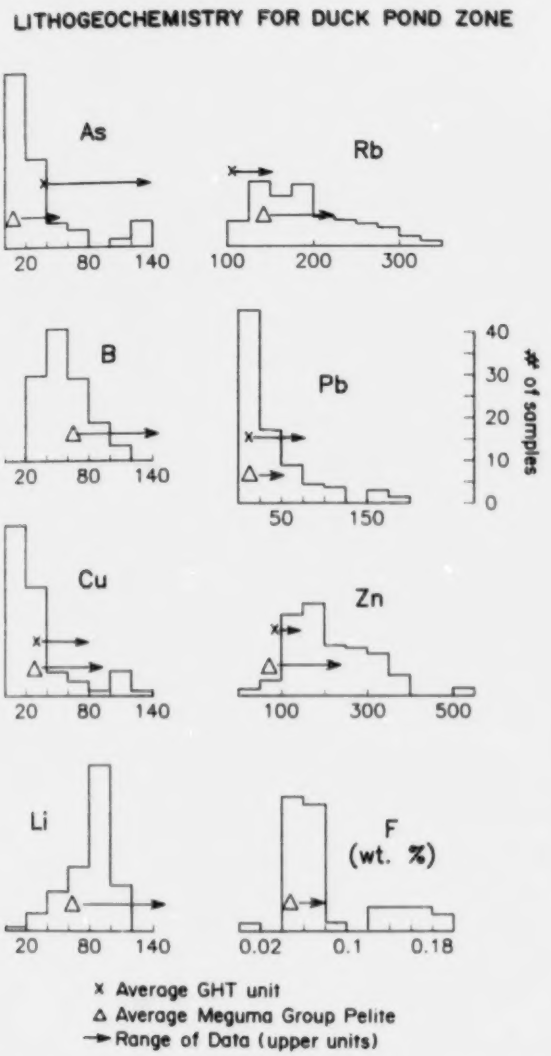

Figure 3. Histogram plots summarizing some of the lithogeochemistry (n=82) of mineralized and barren sedimentary rocks from the Duck Pond Zone. The triangle represents the average and the arrow the upper range for unmineralized pelite as determined on 26 samples from the Goldenville Formation of the eastern Meguma Terrane (S. L. Douma, personal communication, 1990) while the X represents the average for the Goldenville-Halifax transition unit (from data in Graves and Zentilli, 1988).

chemical conditions during growth. The chemistry of both the chlorite and garnet, in addition to their mode of occurrence and textural features, indicates that these minerals are of hydrothermal origin and that their formation accompanied the mineralizing process.

Kempt Snare Lake (Pb, Zn, W, Cu, Ag)

The Kempt Snare Lake mineralized centre occurs approximately 3 km southwest of the Davis Lake Pluton (Fig. 1). It consists of mineralized quartz veins within a greisenized granite cupola that intruded quartzitic sediments of the Goldenville Formation. Previous work included sinking of a 23 m shaft on a 2 m wide mineralized quartz vein (2% combined Pb+Zn, 0.5% Cu, and up to 61 ppm Au and 153 ppm Ag) in 1928, till geochemical surveys, and an induced-polarization survey that identified a high chargeability zone near the shaft (Jensen, 1987). Based on geophysical data, Falconbridge Ltd. drilled three holes (202 m total) to test the mineralized centre. Using drill core samples and dump material, Soehl (1988) and Soehl *et al.* (1989) examined the mineralogy and chemistry of the mineralized system and a more extensive lithogeochemical study has been completed by O'Reilly (unpublished data).

In addition to the sedimentary lithologies, various types of grey to black quartz-, feldspar- and muscovite-bearing greisens and relatively fresh leucogranite lithologies occur in drill core. The freshest granite occurs as either fine grained leucogranite (<2% biotite) or coarse grained leucomozogranite (5% biotite). The leucomonzogranite represents the deepest penetration of one of the drillholes and texturally and mineralogically resembles the coarse grained, K-feldspar megacrystic leucomonzogranite unit of the nearby Davis Lake Pluton (Fig. 1). The leucomonzogranite always occurs in fault contact with other lithologies; hence, its relationship (i.e. intrusive, fault emplacement) to the other rock units remains uncertain.

The granites (representative analyses in Table 1) are enriched in silica, alkalis, Rb, Li and U and are depleted in Ti, Mn, Ba, Sr, Zr, Ta and Hf compared to most phases of the South Mountain Batholith (Ham *et al.*, 1989). Chondrite-normalized rare-earth element patterns for one leucomonzogranite and two leucogranites (Fig. 6) are generally similar to profiles for late-stage differentiates within the South Mountain Batholith (Clarke and Muecke, 1981; Kontak *et al.*, 1988) with slightly fractionated patterns for the light rare-earths but unfractionated patterns for the heavy rare-earths. The pronounced negative Eu anomalies [$(Eu/Eu^*)_N$=0.046 to 0.125] reflect feldspar fractionation, consistent with low abundances of Ba, Sr and Pb in the whole rocks (Table 1). Chemically the granitic lithologies are

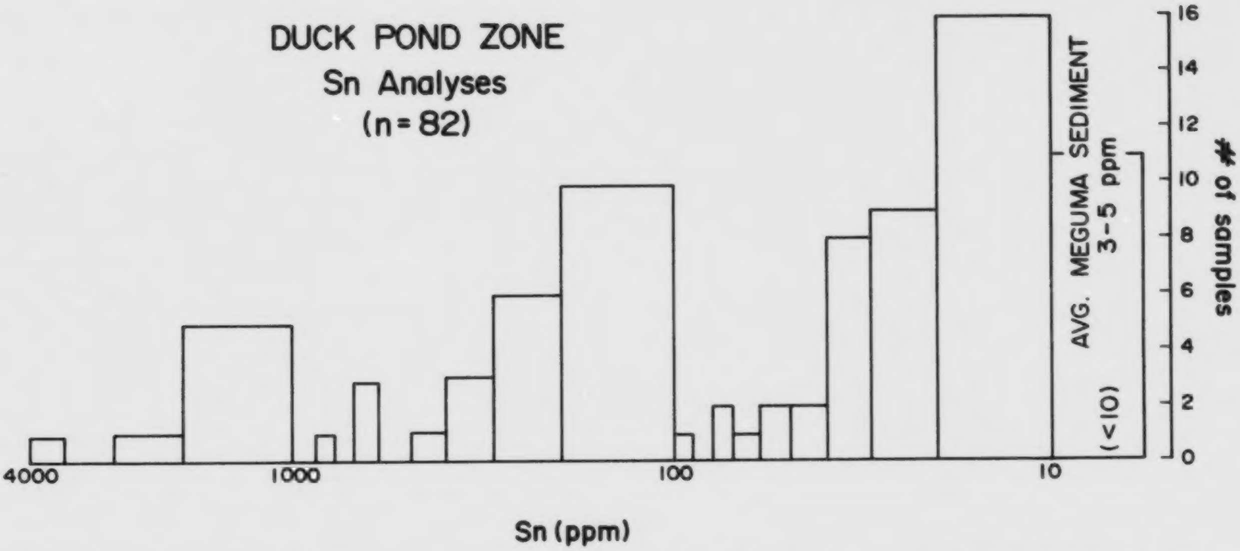

Figure 4. Histogram (log scale) summarizing Sn lithogeochemistry for mineralized and barren sedimentary rocks from the Duck Pond Zone compared to the range for unmineralized pelites from the Meguma Group (S. L. Douma, personal communication, 1990).

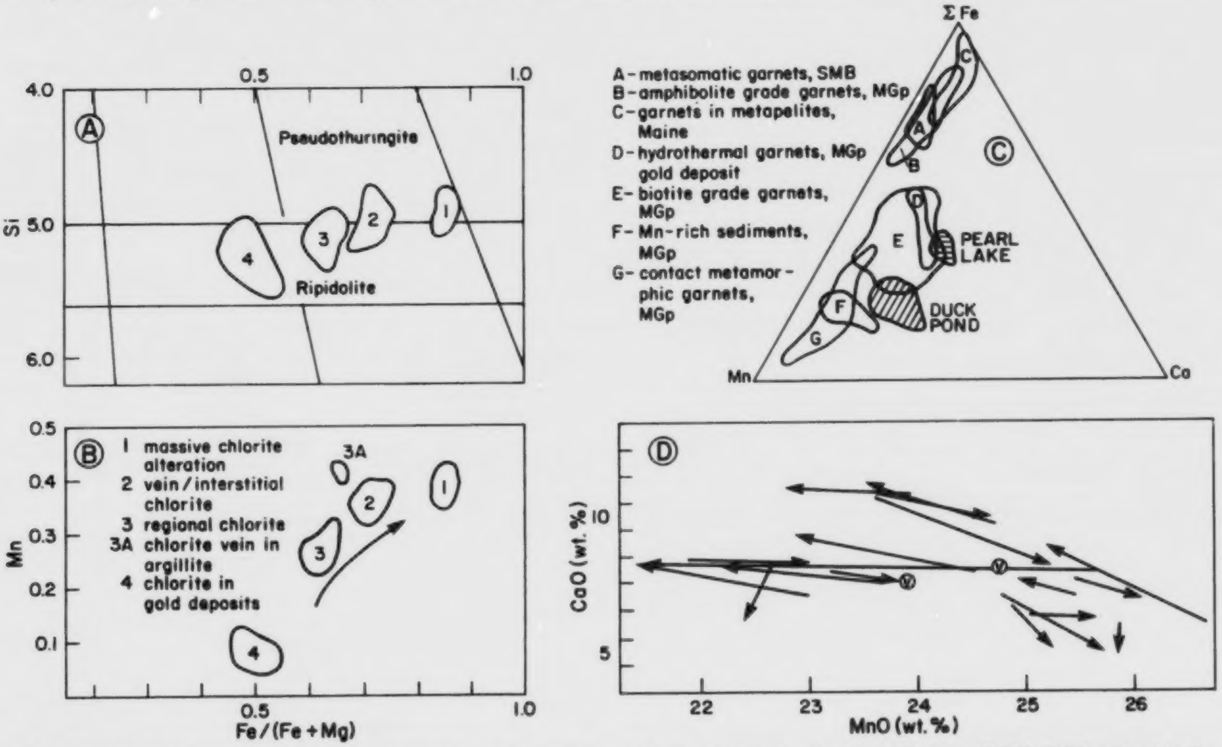

Figure 5. Mineral chemistry of chlorite and garnet from the Duck Pond Zone. (a) Chlorite chemistry (Si versus Fe/(Fe+Mg)) plotted in the classification diagram of Hey (1954). Fields (1, 2, 3, 4) for different samples explained in Fig. 5b. (b) Mn versus Fe/(Fe+Mg) for chlorites showing enrichment in both Fe and Mn for hydrothermal chlorite from the Duck Pond Zone compared to chlorite from regional metamorphic rocks and vein chlorite in lode gold deposits within the Meguma Group (e.g. Beaver Dam). (c) Ternary plot (mole% Fe-Mn-Ca) for garnets in the Duck Pond Zone compared to fields for garnets in different geological environments within the Meguma Group (granite- and sediment-hosted). Data for garnets in amphibolite grade metapelites from Maine in Tracey et al. (1976). (d) CaO versus MnO for garnets showing core-rim zonation (arrow points towards rim). V indicates vein garnet.

Table 1. Representative chemical analyses of granites from East Kemptville (EK) and Kempt Snare Lake (KS) mineralized centres.

	EK-03	EK-09	EK-23C	EK-1075	KS-1-2	KS-3-3	KS-2-8
SiO_2	73.16	73.11	72.32	73.50	75.81	76.17	76.69
TiO_2	0.00	0.08	0.00	0.02	0.07	0.06	0.10
Al_2O_3	15.10	14.52	14.58	15.70	12.88	12.89	12.46
Fe_2O_3	0.18	0.19	0.16	0.28	0.36	0.35	0.43
FeO	0.87	0.87	1.03	0.93	0.67	0.60	0.60
MnO	0.06	0.04	0.04	0.05	0.05	0.05	0.09
MgO	0.03	0.03	0.03	0.02	0.72	0.61	0.69
CaO	0.64	0.46	0.44	0.49	0.49	0.32	0.49
Na_2O	3.59	3.81	3.68	3.88	4.50	4.24	4.55
K_2O	4.08	3.84	3.93	3.86	3.50	3.57	2.95
P_2O_5	0.60	0.49	0.49	0.45	0.08	0.09	0.08
LOI	0.83	0.71	0.76	0.35	1.30	0.90	1.20
F	0.65	1.15	0.69	0.46	0.19	0.13	0.40
	99.79	99.30	98.15	99.99	100.62	99.98	100.73
F=O	0.27	0.48	0.28	0.19	0.07	0.05	0.16
Σ	99.52	98.82	97.87	99.80	100.55	99.93	100.57
(ppm)							
B	<10	<15	<10	-	12	11	14
Li	170	234	417	500	125	135	133
Rb	44	892	963	822	540	465	522
Sr	60	33	77	33	61	31	43
Ba	ND	ND	ND	17	74	78	60
Pb	20	30	34	59	16	22	41
Ga	32	33	38	31	22	21	19
Nb	32	33	31	27	11	13	12
Zr	28	28	30	33	63	55	76
Co	0.3	-	0.4	0.1	-	-	-
U	21	19	27	23	28.5	25.9	26.4
Th	5	5	5	6	24	15	25
Sn	77	110	97	155	5	5	5
W	14	21	24	12	6	6	11
Cu	65	13	113	23	1	1	4
Zn	177	43	286	66	30	142	60
Mo	4	4	7	2	2	2	2
Sc	2.1	1.8	1.9	1.9	-	-	-
Ta	14	10	11	11.2	3.3	5	3.2
Hf	2	0.3	1.9	2.1	3	3	5
Cs	33	39	39	32	13	8.3	10

consistent with highly evolved compositions (e.g. K/Rb = 46 to 62) and are interpreted to represent residual melts formed from crystal fractionation of a relatively more mafic magma of monzogranitic composition.

The dark colour of the greisenized lithologies is attributed to the presence of finely disseminated graphite, which is observed to replace feldspars in greisen lithologies. This has been confirmed by C analyses (0.03 to 0.71 wt.% C; Fig. 7). Positive correlations between C and elements indicative of hydrothermal alteration (e.g. K_2O and H_2O) suggest that the C was introduced during the hydrothermal alteration stage. A $\delta^{13}C$ signature of -27 per mil indicates a biogenic origin for the graphite, probably from Meguma Group lithologies, although this does not ascertain whether the carbon originated from an exsolved fluid phase from a previously contaminated felsic magma or whether

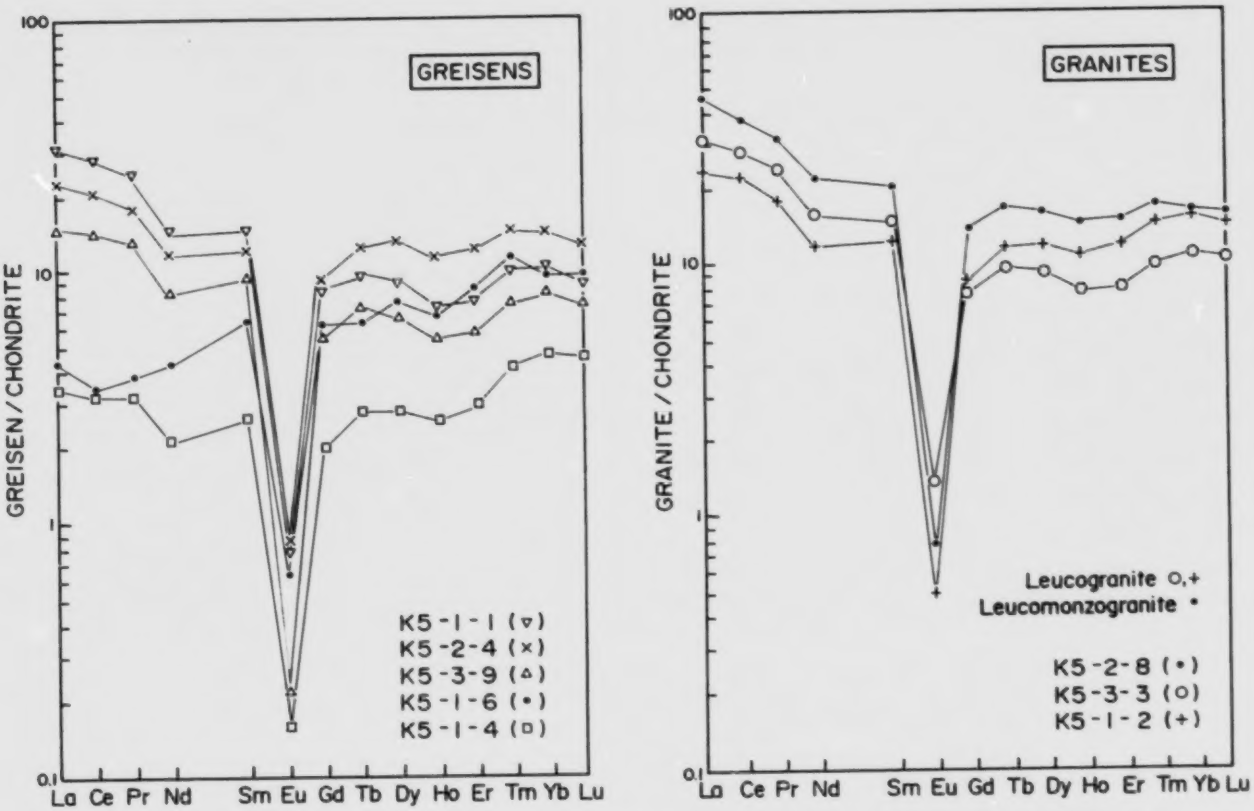

Figure 6. Chondrite-normalized rare-earth element profiles for unmineralized granite and mineralized greisen from Kempt Snare Lake.

introduction of carbon occurred during convection of a hydrothermal fluid phase through the enveloping Meguma Group lithologies.

Mineralization, consisting of arsenopyrite > sphalerite > galena > scheelite > chalcopyrite > Fe-sulphides (+/- carbonate, fluorite), occurs in greisens and quartz vein swarms from 1 mm to 1 m in width. Electron microprobe analysis of galena indicates it contains up to 0.21 wt.% Ag and is, therefore, the main repository for this precious metal. Representative analyses of mineralized veins and greisens are given in Table 2. Alteration of the granitic lithology reflects overall addition of K, Al, H_2O, Rb and C with depletion of Si, Na, Ca and Sr. Chondrite-normalized rare-earth element plots of greisen lithologies (Fig. 6) reflect an overall depletion of both the light and heavy rare-earth elements compared to unaltered granite as a consequence of fluid infiltration and stripping of the rare-earth elements via anionic complexes (F, Cl, CO_2).

Abundant deformational textures indicate a complex structural history for the deposit area. Both ductile (mylonites) and brittle (fracturing, faulting) features are present and textural observations indicate that deformation in part overlapped mineralization. Hence, hydrothermal activity was probably in part facilitated by a favourable structural environment.

^{40}Ar/^{39}Ar dating of two muscovite samples from greisen lithologies gave internally discordant age spectra with a maximum apparent age of ca. 330 Ma and initial ages of ca. 270 Ma for the low temperature parts of the age spectra (Soehl *et al.*, 1989). These ages are similar to other radiometric ages obtained for samples from within the East Kemptville Shear Zone and are considered to reflect overprinting tectono-thermal events.

East Kemptville Tin Deposit

The East Kemptville tin deposit (initial reserves 56 x 10^6 t of 0.165% Sn; Moyle, 1985), representing North America's only primary tin producer, is a greisen-type deposit. Mineralization is hosted by greisenized muscovite-topaz leucogranite located along the western contact of the Davis Lake Pluton where it intrudes Meguma Group metasedimentary rocks (Fig. 1). The deposit was discovered in the late 1970s as part of a regional tin exploration program undertaken by Shell Canada Resources Ltd. It was purchased in 1982 by Rio Algom Ltd. and a consortium of banks. It is currently owned and operated by Rio Kemptville Tin Corporation as an open pit operation milling about 10,000 t/day of Sn-Zn-Cu-Ag ore. The geology of the deposit area has been described by Richardson *et al.* (1982), Richardson (1983, 1988a, 1988b), Kontak *et al.* (1986), Chatterjee *et al.* (1985a) and Kontak (1987, 1988, 1990).

The topaz-muscovite leucogranite host rock is characterized by its medium grained, equigranular texture and the presence of magmatic muscovite and topaz. Geochemically (representative analyses in Table 1) the leucogranite is characterized by elevated abundances of F, P, Li, Rb, U, Sn, W and Cs and depleted levels of B, Ba, Zr, Cr, Co, V, Sc, Mg and Ti compared to leucogranites in the South Mountain Batholith (Fig. 8). Both trace element chemistry and rare-earth element data (chondrite-normalized patterns in Fig. 9) indicate that the leucogranite in the vicinity of the ore zone represents a late stage differentiate, the product of protracted crystal fractionation of a felsic melt which was facilitated by the presence of elevated abundances of volatiles (e.g. F). In terms of Li, Rb and F the leucogranite corresponds to other topaz granites associated with tin mineralization (Taylor *et al.*, 1985).

Tin mineralization within the deposit occurs in two forms: (1) disseminated cassiterite ± Fe-Cu-Zn sulphides + graphite in fine- to medium-grained, dark grey to black, quartz-topaz greisens, and (2) as northeast-trending, subvertical to flat, symmetrically zoned, quartz-topaz ± muscovite greisens cored by coarse cassiterite. The former type of mineralization accounts for most of the ore at East Kemptville and is preferentially located at granite-sediment contacts (Fig. 10); ore grades diminish inward from the contact such that the central part of the ore body is dominated by relatively barren leucogranite. The topaz-boardered cassiterite veins (type 2 greisen) occur throughout the deposit area (i.e. within type 1 greisens and fresh leucogranite). Sulphide mineralization occurs as fine disseminations in the cassiterite-bearing greisens or in paragenetically later quartz-sulphide veins.

Representative chemical analyses of various greisens are provided in Table 3 and include the following types: (1) black, graphite-bearing greisen (EK-016), (2) massive cassiterite-topaz greisen (EK-017), (3) zoned topaz greisen cored by cassiterite (EK-05), (4) greenish sericite-topaz greisen (EK-23D), (5) sericitized granite (EK-95A) and topaz greisen (EK-95B), (6) zoned topaz greisen (EK-120A, B), (7) green sericite greisen (EK-026), and (8) whitish sericite greisen (EK-116). There has been massive depletion/enrichment in the greisen relative to fresh leucogranite with mobility of most elements, including the rare-earths which show highly fractionated patterns (light rare-earth element depletion and heavy rare-earth element enrichment) compared to fresh leucogranite (Fig. 9). The greisens are variably enriched in Li, Rb, W and Bi, but consistently show low abundances of B, Mo and Sb.

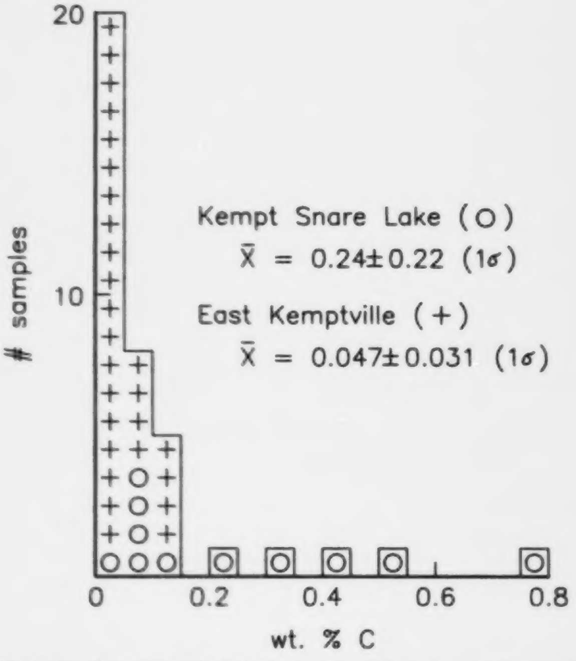

Figure 7. Histogram plot of wt.% C for greisen samples from the East Kemtpville and Kempt Snare Lake deposit areas. These data confirm the presence of graphite in the greisen zones.

Stable isotope studies (S, O) at East Kemptville are summarized in Figures 11 and 12. δ^{34}S data for 32 sulphides (pyrite, pyrrhotite, chalcopyrite, arsenopyrite, sphalerite, galena) representing all stages of mineralization indicate a very narrow compositional range near 5 per mil. The data compare favourably with additional results from other granite-hosted deposits in southern Nova Scotia and contrast with Meguma Group mineralization which is enriched in heavy S

Table 2. Representative chemical analyses of greisens from Kempt Snare Lake (KS).

	KS-1-6	KS-3-9	KS-4472	KS-4473	KS-4448
SiO_2	70.02	75.43	-	-	-
TiO_2	0.09	0.04	-	-	-
Al_2O_3	15.70	13.39	-	-	-
Fe_2O_3	0.69	0.44	-	-	-
FeO	1.27	0.70	-	-	-
MnO	0.12	0.04	-	-	-
MgO	0.80	0.73	-	-	-
CaO	0.06	0.31	-	-	-
Na_2O	1.42	4.54	-	-	-
K_2O	6.63	3.39	-	-	-
P_2O_5	0.09	0.09	-	-	-
LOI	2.70	1.22	-	-	-
F	0.20	0.23	1.10	0.25	0.07
(ppm; Au ppb)					
B	55	12	24	39	37
Li	228	154	109	87	84
Rb	901	625	-	-	-
Sr	14	20	-	-	-
Ba	99	23	-	-	-
Pb	6	26	69	139000	5400
Ga	31	26	-	-	-
Nb	16	14	-	-	-
Zr	79	49	-	-	-
Co	-	-	3	2	1
U	30	33.7	20	20	10
Th	20	16	12	12	4.6
Sn	16	5	9	20	7
W	25	22	14.60	10	8
Cu	1	1	11	44	72
Zn	436	45	89	88	70600
Mo	3	6	2	3	2
Sc	-	-	2.4	1.9	1.1
Ta	4.2	5.5	3	4	1
Hf	4	3	-	-	-
Cs	13	12	8	10	4
Ag	0.1	0.1	0.1	191	6.6
Au	<4	<2	5	35	6
As	1020	58	330	4300	1320
Bi	0.04	0.05	1.0	290	13
Cd	-	-	0.9	59	1680
Y	75	44	-	-	-
Sb	-	-	0.2	2.8	5

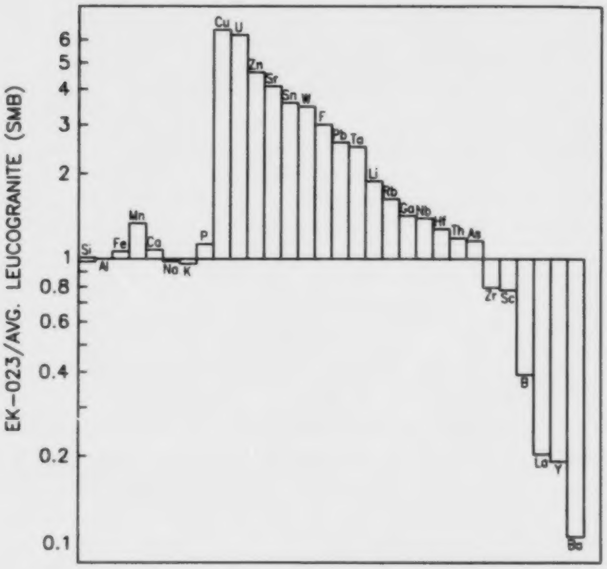

Figure 8. Normalized plot of a sample of unmineralized East Kemptville leucogranite (collected from within the ore deposit area) compared to the average leucogranite from the eastern half of the South Mountain Batholith (data in Ham et al., 1989).

(Fig. 11). The results for East Kemptville favour a magmatic source for the S. Oxygen isotope data for quartz from the main mineralizing stages have been used to calculate the evolutionary path of $^{18}O_{fluid}$ in conjunction with fluid inclusion thermometric data. The results indicate that initial fluids had an ^{18}O signature of 6-7.5 per mil but that later stages of mineralization are characterized by a progressive decrease in $^{18}O_{fluid}$. The oxygen isotope data suggest possible mixing of a primary magmatic fluid with a fluid characterized by lighter ^{18}O values, probably of meteoric origin.

Overprinting both the leucogranite and greisen lithologies are various structural fabrics ranging from ductile to brittle in nature. The deformation is pervasive on all scales with planar fabrics (mylonites, cleavages) having a preferred northeast, subvertical trend.

Previous attempts to date the host rock and associated mineralization indicated ages from ca. 300 Ma to 330 Ma (Zentilli and Reynolds, 1985; Richardson *et al.*, 1988). More recent Pb-Pb, Rb-Sr (Fig. 13) and $^{40}Ar/^{39}Ar$ studies (Kontak *et al.*, 1989, 1990b) indicate initial intrusion and mineralization at ca. 370 Ma with subsequent resetting of isotopic systems at 340 Ma, 324 Ma, 300 Ma and 250 Ma. Hence, the East Kemptville leucogranite, and associated mineralization, is a temporal equivalent of the South Mountain Batholith, albeit with several subsequent, overprinting tectono-thermal events.

Dominique Deposit

The Dominique deposit area is located 4-5 km east of Yarmouth within metasedimentary rocks of the Goldenville Formation (Fig. 14). Mineralization in

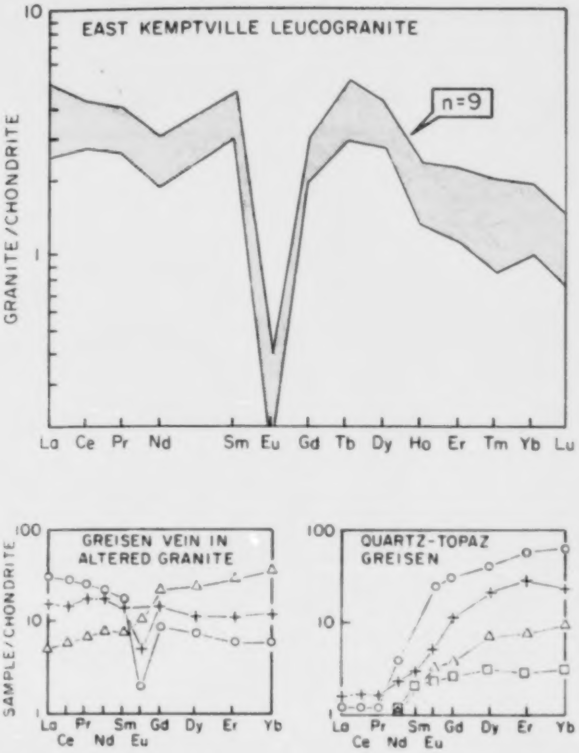

Figure 9. Chondrite-normalized rare-earth element plots of unmineralized leucogranite and variably mineralized greisens from the East Kemptville deposit. Data for the greisens from Chatterjee and Strong (1984).

the area was first discovered by the Millmore Syndicate during 1976 in the form of mineralized boulders of Meguma Group metasedimentary rocks in kame gravel on the west side of the Tusket River. The property was subsequently optioned by Shell Canada Resources Ltd. and from 1976-1982 till geochemistry and geophysical surveys identified potential mineralized sites which were tested with 89 diamond-drill holes (Fig. 15). Exploration efforts delineated several east-trending mineralized zones containing high-grade intersections (e.g. 4.14 m (apparent width) of 0.72% Sn, 2% Zn) of tin mineralization associated with chloritic alteration. Despite the encouraging early results little follow-up work on the area has been done. Research efforts directed at the area are summarized in Chatterjee *et al.* (1985b) and Wolfson (1983).

The Dominique area is located just north of the 315 Ma old Wedgeport pluton (Cormier *et al.*, 1988), which consists of a biotite granodiorite facies in the southern half and a more evolved, two-mica monzogranite facies in the northern part. The presence of miarolitic cavities, aplite-pegmatitite segregation, quartz-tourmaline veins and felsic dykes indicates that the intrusion evolved into a water-saturated felsic melt in later stages of crystallization. Petrographically and geochemically the more evoled phase of the pluton shows pervasive hydrothermal alteration, presumably related to the presence of endo-contact Sn, W, Mo, Bi, Ag and base metal mineralization within greisenized granite. The greisen zones, a few centimetres to over 3 m, vary from muscovite-rich to quartz dominant with additional phyllosilicates, topaz, fluorite, beryl, tourmaline and carbonates which contain the aforementioned ore assemblage. The granite is cut by northeast-trending shear faults which are locally greisenized. A more detailed description of the Wedgeport pluton is found in Chatterjee *et al.* (1985b).

The Goldenville Formation in the area is tightly folded into north-plunging structures, as outlined by a rusty-weathering schist unit with a prominent geophysical signature (Fig. 14), that are crosscut by northeasterly-trending faults and shear zones. The Acadian slaty cleavage is crenulated by a later fabric, probably related to the same deformation as the faulting and shearing within this area and elsewhere in the East Kemptville Shear Zone (Fig. 1).

Mineralization in the Dominique deposit occurs as quartz ± chlorite ± carbonate zones in fractures with pyrite, pyrrhotite, arsenopyrite, chalcopyrite, galena and cassiterite. Tin mineralization is strongly associated with chloritic alteration, reminiscent of the high-grade (Sn) chloritic lode systems of Cornwall, England, and some Andean deposits (e.g. San Rafael, Peru; Palma and Clark, 1982), and may occur exclusive of sulphides; hence, high-grade tin zones may not be detected using geophysical methods. The mineralized zones occur as northeast- to east-trending structures that crosscut the main, north-plunging anticlinal structure in the area. The poor correlation of mineralized zones between drillholes suggests that the zones may represent steeply plunging, pipe-like structures.

The presence of tin and base metal mineralization in metasedimentary rocks immediately north of the mineralized and altered Wedgeport pluton suggests a relationship between the two. It is suggested that the granite extends to the north beneath the Dominique area and that fluids from the granite migrated up favourable structures in the overlying Meguma Group metasediments.

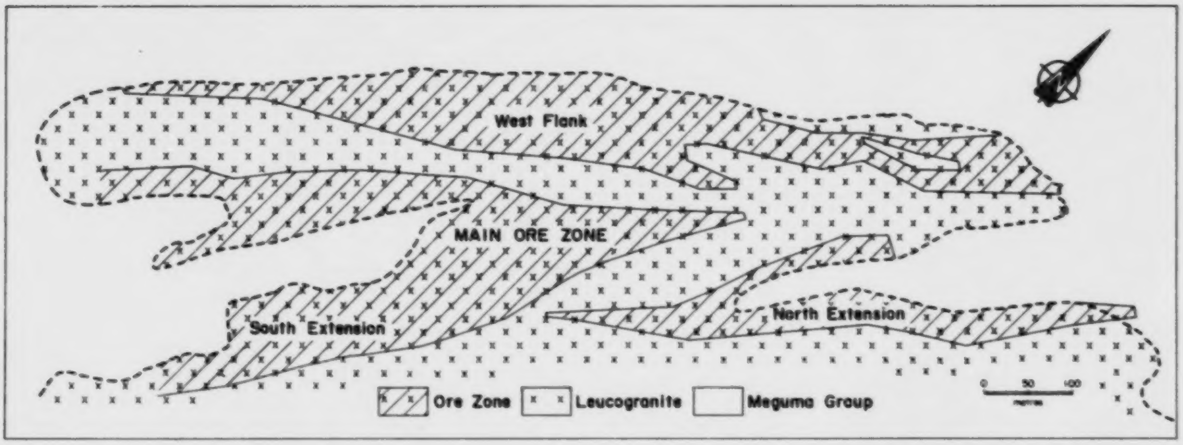

Figure 10. Plan map of the East Kemptville tin deposit (note that the Baby Zone, which occurs to the south of the deposit area shown, is not included in this diagram) showing the distribution of the ore zones and close association of economic zones of mineralization with proximitiy to granite-sediment contact (after C. Poulin, personal communication, 1989). In these latter areas the dark, sulphide- and cassiterite-bearing topaz greisens dominate. Note that mineralization occurs in the core of the deposit, albeit in insufficient quantities to be economically recovered.

Pearl Lake

The Pearl Lake mineralized centre was explored by Kerr Addison Gold Mines Ltd. during 1977-78. Various types of sulphide associations were identified as vein fillings; however, no mention of tin mineralization was recorded by company geologists. The presence of cassiterite mineralization was confirmed by Chatterjee (1980) who reported assays of up to 0.54% Sn for mineralized vein stockwork.

Mineralization, strikingly similar to that found at Dominique and Duck Pond, is hosted by interbedded slates and quartzites of the Meguma Group. The host rocks have been metamorphosed to above the garnet isograd in this region. Fracture fillings and vein stockwork vary from 1 to 8 cm in width and have alteration halos (silica, chlorite, garnet). Vein mineralogy comprises quartz, carbonates, fluorite, garnet, sphene, chlorite, cassiterite and Cu, Zn and Fe sulphides. Compositions of the garnets found in alteration halos bordering veins are characterized by equal proportions of Ca-Fe-Mn (mole%, Fig. 5c). Although the garnet compositions overlap the field for regional grade garnets in the Ca-Fe-Mn ternary plot, textural evidence favors a hydrothermal origin for the garnets.

IMPLICATIONS FOR TIN MINERALIZATION IN THE MEGUMA TERRANE

The coincidence of tin mineralization in southwest Nova Scotia with a major northeast-trending structure is reminiscent of linear trends found in other tin metallogenic provinces world-wide. For example, linear arrangements of mineralized intrusions occur within the Nigerian, Central Andean (i.e. SE Peru - NW Bolivia), Australian and Cornish tin provinces and, as others have postulated, we infer that there is an important causative association involved. In addition, we note that in other parts of the South Mountain Batholith (i.e. Dean and Chapter Mn mines, Millet Brook U deposit) there is a strong structural control to mineralization.

Although granite cupolas have not been detected beneath all the mineralized centres hosted by Meguma Group metasedimentary rocks, the presence of a granite cupola beneath the Kempt Snare Lake mineralized zone, which is strikingly similar to the dark greisens at East Kemptville, and the inferred presence of granite beneath the Dominique deposit area suggest that granites probably underlie the remaining mineralized sites (Pearl Lake, Duck Pond). Hence, at present, we

Table 3. Representative chemical analyses of greisens from East Kemptville (EK).

	EK-05	EK-016	EK-17	EK-23D	EK-26	EK-116	EK-95A	EK-95B	EK-120A	EK-120B
SiO_2	71.91	72.57	46.71	72.13	72.29	63.35	70.74	72.76	71.51	27.76
TiO_2	0.04	0.00	0.00	0.08	0.04	0.02	0.05	0.02	0.13	
Al_2O_3	17.82	11.86	16.48	14.12	14.26	18.96	16.18	15.69	17.18	43.38
Fe_2O_3	2.90	4.26	1.72	3.20	2.57	5.45	4.06	2.72	2.24	3.53
FeO	-	-	-	-	-	-	-	-	-	-
MnO	0.02	0.12	0.04	0.11	0.10	0.18	0.06	0.11	0.04	0.06
MgO	0.00	0.05	0.03	0.13	0.07	0.05	0.06	0.08	0.02	0.06
CaO	0.46	0.60	0.32	0.68	0.92	0.79	0.63	0.68	0.78	0.67
Na_2O	0.21	4.26	0.16	0.49	0.10	0.56	0.30	1.25	0.20	0.31
K_2O	0.42	0.04	0.82	4.65	5.10	6.54	2.19	4.21	0.61	1.90
P_2O_5	0.42	0.37	0.22	0.60	0.39	0.53	0.37	0.46	0.57	0.46
LOI	2.18	2.03	1.18	2.01	2.60	0.95	2.41	1.29	0.64	1.63
F	3.42	1.86	1.66	1.40	0.96	0.90	1.16	1.24	3.42	3.63
(ppm; Au ppb)										
B	<10	<10	-	<10	40	-	-	-	-	-
Li	28	28	172	751	283	1680	362	850	159	542
Rb	37	1492	280	1622	1178	2319	593	1201	177	655
Sr	38	21	161	83	126	24	69	72	41	117
Ba	3	9	10	ND	54	28	10	33	ND	11
Pb	2	4	3	4	4	3	10	4	4	3
Ga	ND	75	26	63	55	70	15	37	8	21
Nb	32	36	528	33	31	20	25	27	42	219
Zr	23	30	26	29	31	33	28	30	31	12
Co	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
U	22	26	12.2	27	29	31	21	27	31	30
Th	4.6	5.4	2.8	4.8	6.3	5.7	3.6	5.4	6.1	6.7
Sn	35000	1260	230000	232	427	860	4000	470	17000	105000
W	59	17	804	21	19	25	140	18	74	130
Cu	10726	301	2802	59	213	773	641	134	6672	11288
Zn	4567	4782	5818	2335	577	1041	436	1642	543	658
Mo	94	8	<8	4	5	<2	6	2	3	21
Sc	0.8	1.5	7.2	2.3	1.4	1.6	1.7	2.5	1.6	4.2
Ta	9	13	123	14	9	6	10	12	12	29
Hf	3	<2	<2	<2	<2	2	2	<2	3	<2
Cs	4	102	11	<3	40	113	26	53	12	36
Ag	3.7	0.9	5.5	0.1	0.7	<5	<5	<5	26	22
Au	22	10	<16	17	25	<5	<5	<5	<5	<5
As	4	18	82	81	11	19	7	13	72	138
Bi	126	<15	15	<15	<15	30	18	<15	36	18
Cd	48	64	44	28	<10	<10	<10	24	<10	<10
Y	5	67	58	70	58	75	22	39	11	18
Sb	<0.2	0.2	<0.2	1.4	<0.2	0.3	0.6	<0.2	0.4	0.5

postulate that sediment-hosted mineralization within the East Kemptville Shear Zone is a surface manifestation of buried granite cupolas; these granites may be similar to the muscovite-topaz leucogranite at East Kemptville.

At least two ages of significant tin - base metal mineralization are represented within the tin domain, ca. 370 Ma (East Kemptville) and ca. 315 Ma (Plymouth Pluton-Dominique). At present it is not possible to say what the extent of the respective age provinces may be and whether additional mineralizing events may be represented.

The linear disposition of leucogranites and other granitoid phases within the Davis Lake Pluton, including the muscovite - topaz leucogranite at East Kemptville, suggests a strong structural control in localizing the intrusions. A similar scenario is suggested for the remaining unexposed intrusions. The strong northeast trend for greisen and quartz-sulphide veins at East Kemptville, Duck Pond and Dominique further emphasizes the importance of structural control for localizing and controlling the

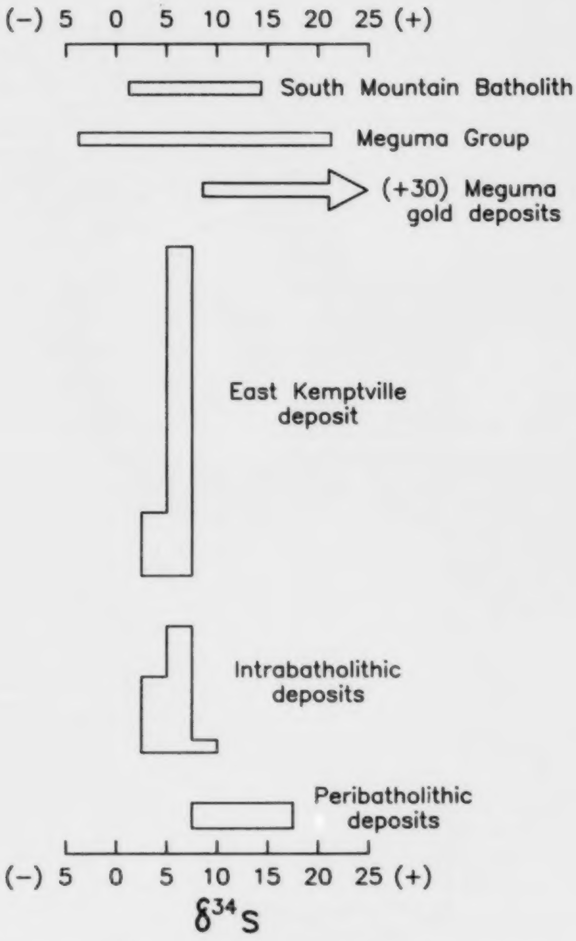

Figure 11. Sulphur isotope data for sulphides (pyrite, pyrrhotite, arsenopyrite, chalcopyrite, sphalerite, galena; n=32) from all stages of mineralization at East Kemptville. Data are compared to sulphur isotope analyses for other base metal and lithophile element mineralized zones in the tin domain and ranges for the South Mountain Batholith and Meguma Group. Diagram modified from Kontak (1990).

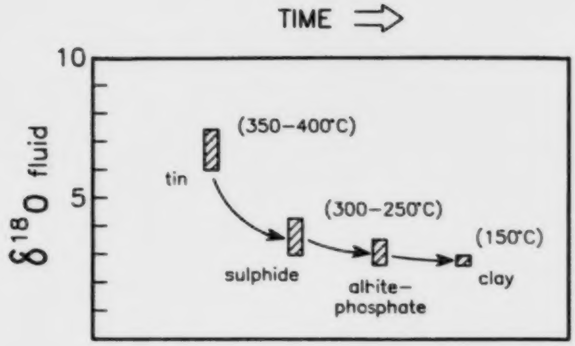

Figure 12. Plot of calculated $\delta^{18}O_{fluid}$ versus time for the different stages of mineralization at the East Kemptville tin deposit. Diagram was constructed using oxygen isotope data (in Kontak, 1988) for coexisting quartz in the mineralizing stages and temperatures were obtained from fluid inclusion thermometry. The trend toward lower values of $\delta^{18}O_{fluid}$ with progressive stages of mineralization suggests incursion of a fluid with a light $\delta^{18}O$ signature, probably meteroic water.

trend of mineralization and the locus of granite intrusion. Thus, we would encourage future exploration efforts to be concentrated in the area of the East Kemptville Shear Zone in order to maximize the potential for future discoveries of additional tin - base metal deposits. The recognition of highly evolved, mineralized felsic intrusions (East Kemptville, Kempt Snare Lake, Wedgeport), enriched in elements (F, Rb, Li, Cs, Sn, W, U) generally considered characteristic of Sn- and W-mineralized granites, within an area hosting numerous zones of tin, base metal and precious metal mineralization suggests that the region offers a high potential for the discovery of additional reserves. The association of tin mineralization with a fluorine-rich topaz granite (East Kemptville leucogranite) is similar to the situation in the Cornish tin fields and to many occurrences of topaz rhyolites or ongonitic suites world-wide. Hence, the association of tin mineralization and a suitable progenitor is another favourable feature of this area.

The features outlined above indicate that the tin domain of southwest Nova Scotia shares many important similarities with other stanniferous provinces. Such provinces are characterized by a plethora of mineralized centres within a relatively small area. The abundance of deposits and occurrences within southwest Nova Scotia mimics this. The apparent structural trend delineated by the mineralized zones and their coincidence with a major zone of deformation suggests an important relationship that should not be ignored, in fact we favour a causative association and suggest that exploration be focused within this zone.

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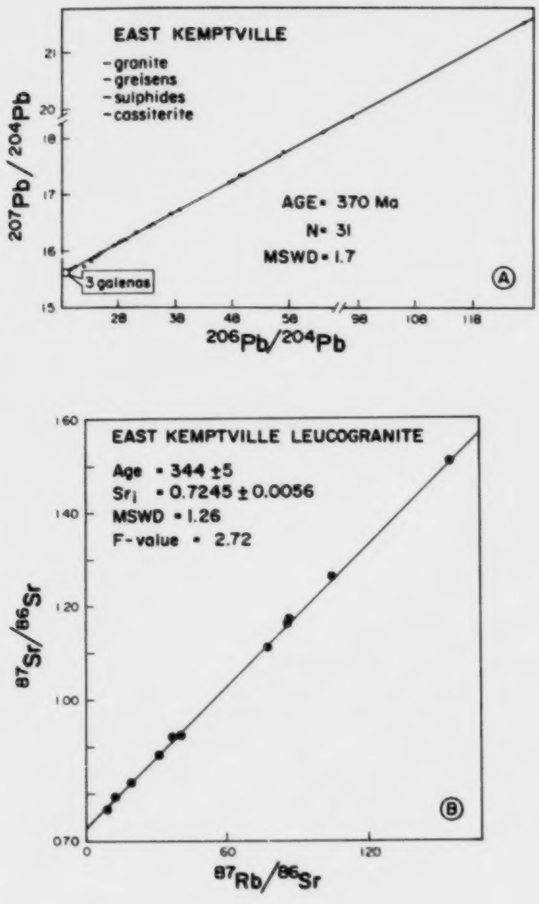

Figure 13. Geochronological data for the East Kemptville deposit area. (a) ^{207}Pb/^{204}Pb versus ^{206}Pb/^{204}Pb diagram for unmineralized leucogranite, greisens, sulphides and cassiterite from the deposit area. Regression of the data (n= 31) indicates an age of 370 Ma and shows that the granite, altered rocks and mineralization are all cogenetic (i.e. formed at the same time) with the Pb in all cases originating from a common reservoir. (b) Rb-Sr whole-rock isochron plot for leucogranites (n=11) indicating an age of 344 ± 5 Ma. This age is interpreted to reflect open system behavior of the whole rocks at ca. 344 Ma related to a thermo-tectonic disturbance.

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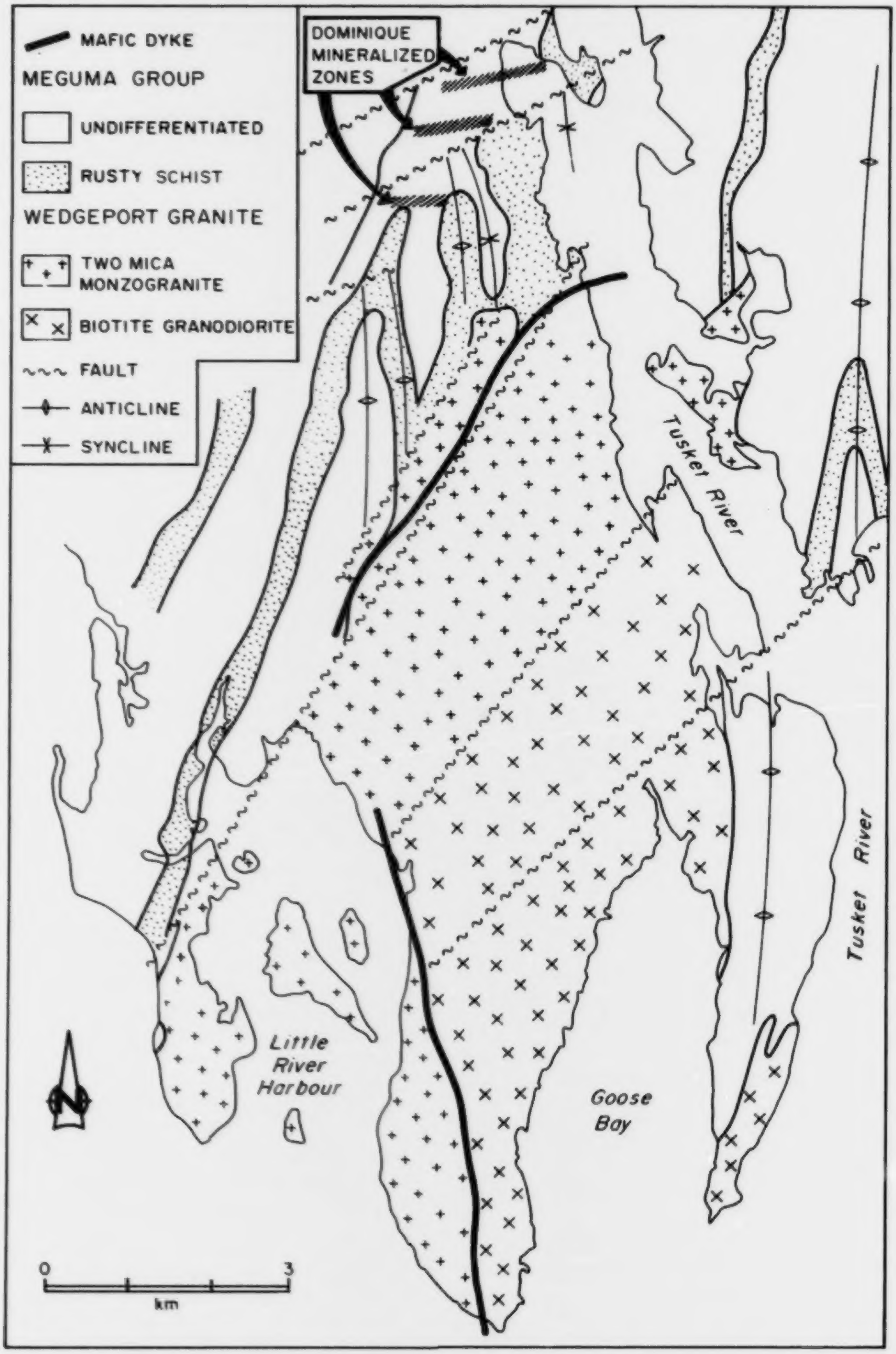
MAFIC DYKE
MEGUMA GROUP
UNDIFFERENTIATED
RUSTY SCHIST
WEDGEPORT GRANITE
TWO MICA MONZOGRANITE
BIOTITE GRANODIORITE
FAULT
ANTICLINE
SYNCLINE
DOMINIQUE MINERALIZED ZONES
Tusket River
Tusket River
Little River Harbour
Goose Bay
N
0
3
km

Figure 14. Geological map of the Wedgeport area showing the extent of the Wedgeport pluton and location of the mineralized zones of the Dominique tin deposit (modified after Chatterjee et al., 1985b).

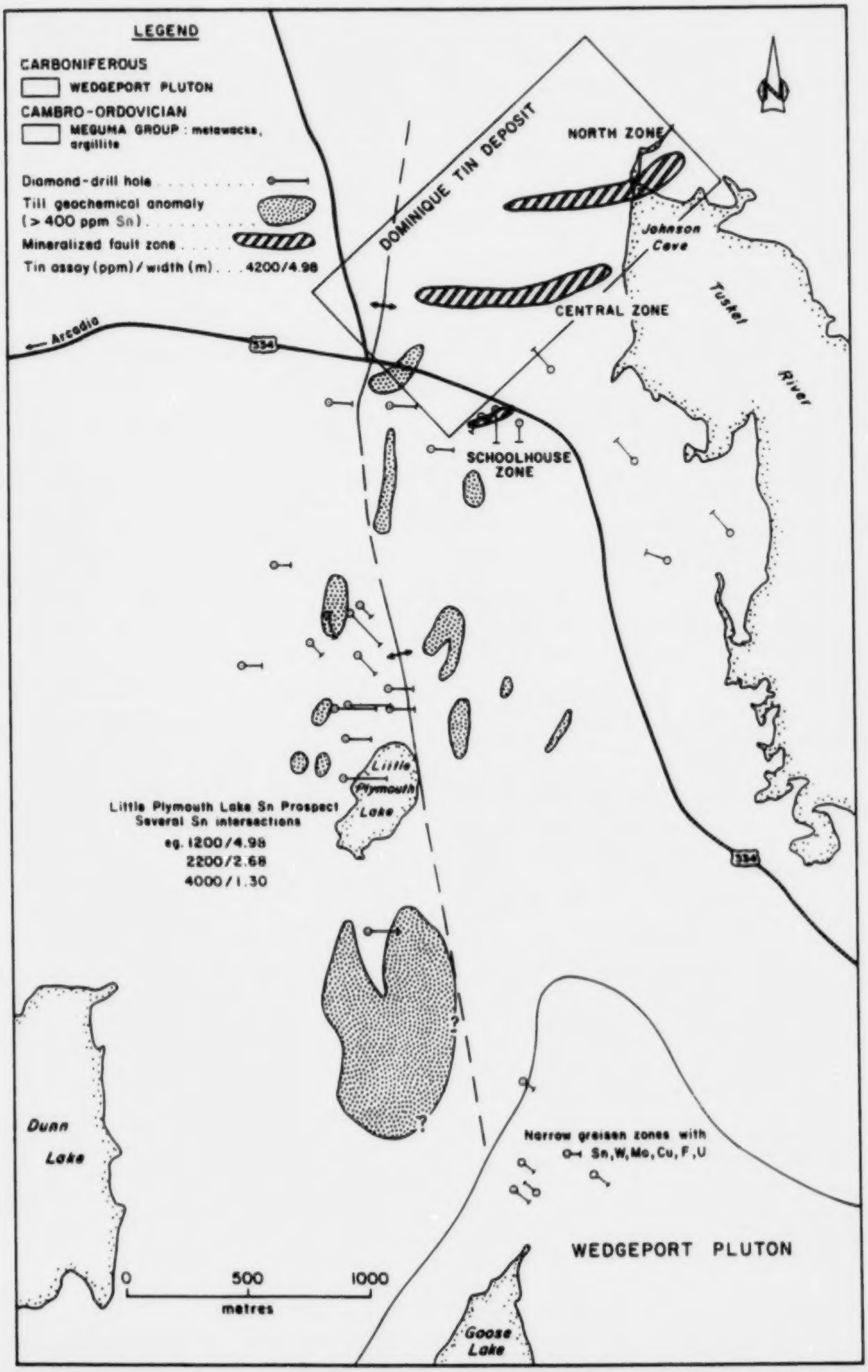
LEGEND
CARBONIFEROUS
WEDGEPORT PLUTON
CAMBRO-ORDOVICIAN
MEGUMA GROUP : metawacke, argillite
Diamond-drill hole
Till geochemical anomaly (> 400 ppm Sn)
Mineralized fault zone
Tin assay (ppm) / width (m) . . . 4200/4.98
N
DOMINIQUE TIN DEPOSIT
NORTH ZONE
CENTRAL ZONE
SCHOOLHOUSE ZONE
Johnson Cove
Tusket River
Arcadia
334
334
Little Plymouth Lake
Little Plymouth Lake Sn Prospect
Several Sn intersections
eg. 1200/4.98
2200/2.68
4000/1.30
?
?
Dunn Lake
Narrow greisen zones with Sn, W, Mo, Cu, F, U
WEDGEPORT PLUTON
Goose Lake
0
500
1000
metres

Figure 15. Distribution of mineralized zones, till geochemical anonalies and diamond-drill holes in the Dominique tin deposit area. The map is based on an unpublished report by L. D. Rankin, who based his report on open assesement reports submitted by Shell Canada Resources Ltd.

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A ^{40}AR/^{39}AR GEOCHRONOLOGICAL STUDY OF METAMORPHIC AND IGNEOUS ROCKS OF THE LISCOMB COMPLEX, SOUTHERN NOVA SCOTIA[1]

D. J. Kontak, A. K. Chatterjee, P. H. Reynolds[2] and K. Taylor[2]

INTRODUCTION

Mapping by P. S. Giles and A. K. Chatterjee of the Nova Scotia Department of Mines and Energy in the Liscomb area of southern Nova Scotia (Fig. 1) during the 1986 field season revealed the presence of previously unrecognized high-grade metamorphic rocks and mafic/gabbroic intrusions that are intruded by peraluminous granitoid rocks (Giles and Chatterjee, 1986, 1987). The area had previously been mapped as the Liscomb Pluton by Faribault (1895), but in consideration of the diverse assemblage of rock types present Giles and Chatterjee (1986) suggested that the name be changed to the Liscomb Complex. The recognition of this rock suite has prompted rethinking of conventional concepts with respect to the magmatic (Clarke and Chatterjee, 1988), metallogenetic (Giles and Chatterjee, 1987; Kontak *et al.*, 1988, 1989a, 1990b) and tectonic evolution of the Meguma Terrane. Although field relationships within the Liscomb area indicate a relative chronology of metamorphic and plutonic events, the lack of radiometric data prevents establishment of an absolute chronology. Hence, in order to remedy this problem, a ^{40}Ar/^{39}Ar dating project was initiated to (1) obtain information on the thermal history of the Liscomb Complex, (2) provide an absolute time frame of events and (3) potentially resolve the genetic relationship among the different units (i.e. single or multiple magmatic and metamorphic events). Preliminary results of this project have been presented elsewhere (Kontak *et al.*, 1989a, 1990a) and here we present the complete set of data (10 biotite, 5 muscovite and 3 amphibole samples) and discuss the results. A more detailed treatment of the data and description of the samples analyzed is in preparation.

GEOLOGICAL SETTING OF THE LISCOMB COMPLEX

The Liscomb Complex, located within the Meguma Terrane of southern Nova Scotia, is surrounded by metasedimentary rocks of the Lower Paleozoic Meguma Group. Meguma Group rocks were metamorphosed (greenschist facies) and deformed during the mid-Devonian Acadian Orogeny ca. 400 Ma ago (Reynolds and Muecke, 1978; Muecke *et al.*, 1988; Keppie and Dallmeyer, 1987). The metamorphic rocks of the Liscomb Complex have a distinct flow foliation, in places gneissic, that is oblique to the Acadian fabric preserved within rocks of the Meguma Group (Fig. 1). Mineral assemblages indicate amphibolite to granulite facies P-T conditions. The Liscomb gneiss contains irregularly-shaped fragments of Meguma Group lithologies that are of lower metamorphic grade and have internal fabrics discordant to those of the host gneiss (Fig. 2a, 2b).

Gabbroic rocks occur in two separate areas, referred to as the Ten Mile Lake and Bog Island intrusions. The physical features of the intrusions, including an assortment of both cognate and exotic xenoliths and sulphide-rich (pyrite, pyrrhotite, chalcopyrite) vesicles (remnant volatile-rich cavities), suggest that the intrusions may represent breccia pipes. These intrusions contain xenoliths of both Liscomb gneiss and Meguma Group lithologies.

Several granitic intrusions are recognized within the Liscomb Complex, ranging from biotite granodiorite to two-mica monzogranite; outlines of these intrusions are indicated in Figure 1. The granites contain xenoliths of Liscomb gneiss lithologies (Fig. 2d) and leucogranite dykes cut the gabbroic intrusions (Fig. 2c).

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[1] Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

[2] Department of Geology, Dalhousie University, Halifax, Nova Scotia

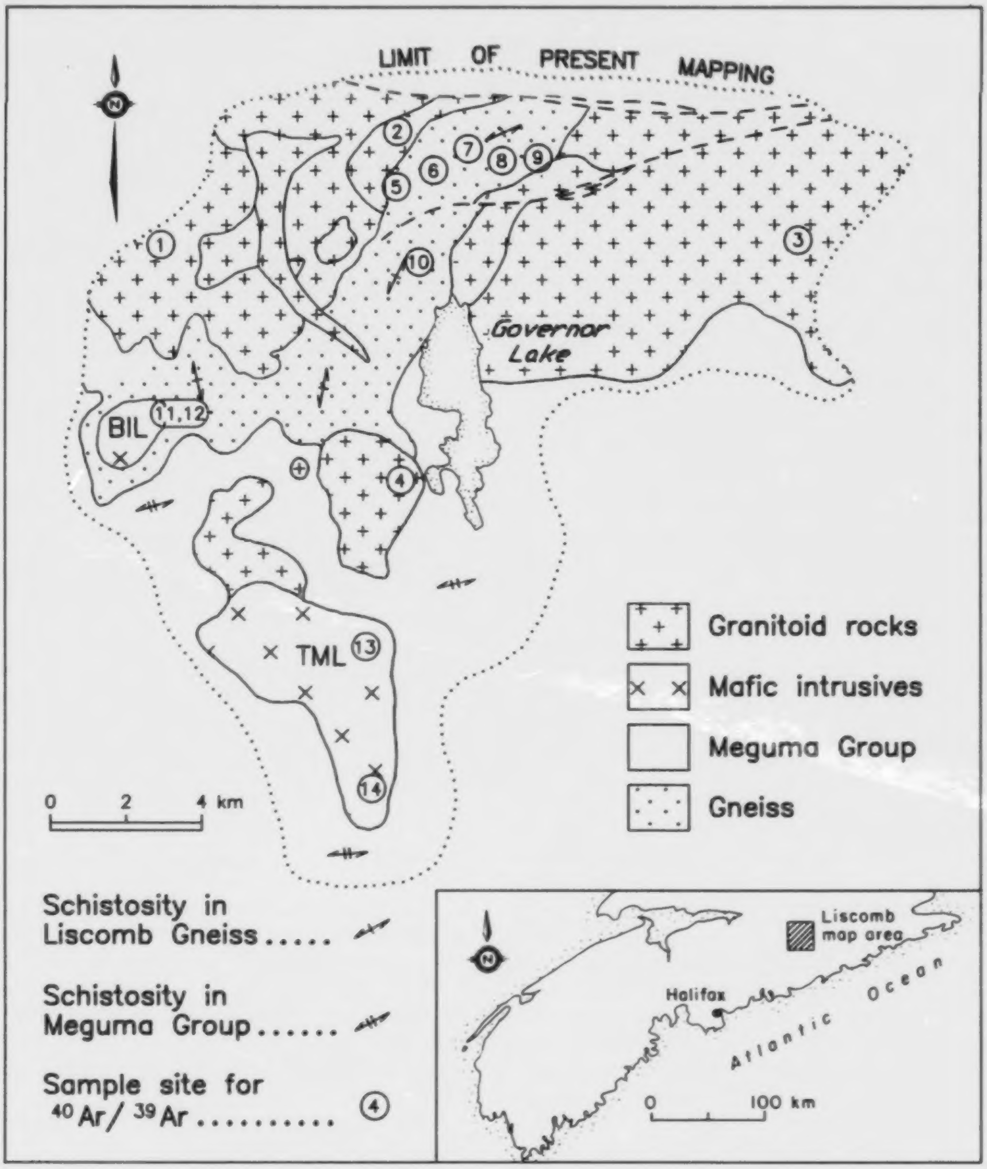
LIMIT OF PRESENT MAPPING
N
1
2
3
4
5
6
7
8
9
10
11,12
13
14
Governor Lake
BIL
TML
0 2 4 km
Granitoid rocks
Mafic intrusives
Meguma Group
Gneiss
Schistosity in Liscomb Gneiss .....
Schistosity in Meguma Group ......
Sample site for $^{40}Ar/^{39}Ar$ ....
Liscomb map area
Halifax
Atlantic Ocean
0 100 km

Figure 1. Simplified geological map of the Liscomb Complex, southern Nova Scotia, showing locations of samples used in the dating study (modified from Giles and Chatterjee, 1986). BIL = Bog Island Lake intrusion; TML = Ten Mile Lake intrusion.

Field relationships indicate the following sequence of events: (1) metamorphism and deformation of Meguma Group lithologies at ca. 400 Ma, (2) emplacement of the Liscomb gneiss, (3) intrusion of the Ten Mile Lake and Bog Island gabbroic bodies and (4) intrusion of granitoid rocks. Similarity of the granitoid rocks to other peraluminous suites in the Meguma Terrane (e.g. South Mountain Batholith) suggests that their intrusion occurred at 370 Ma, coeval with intrusion of the other granitic suites.

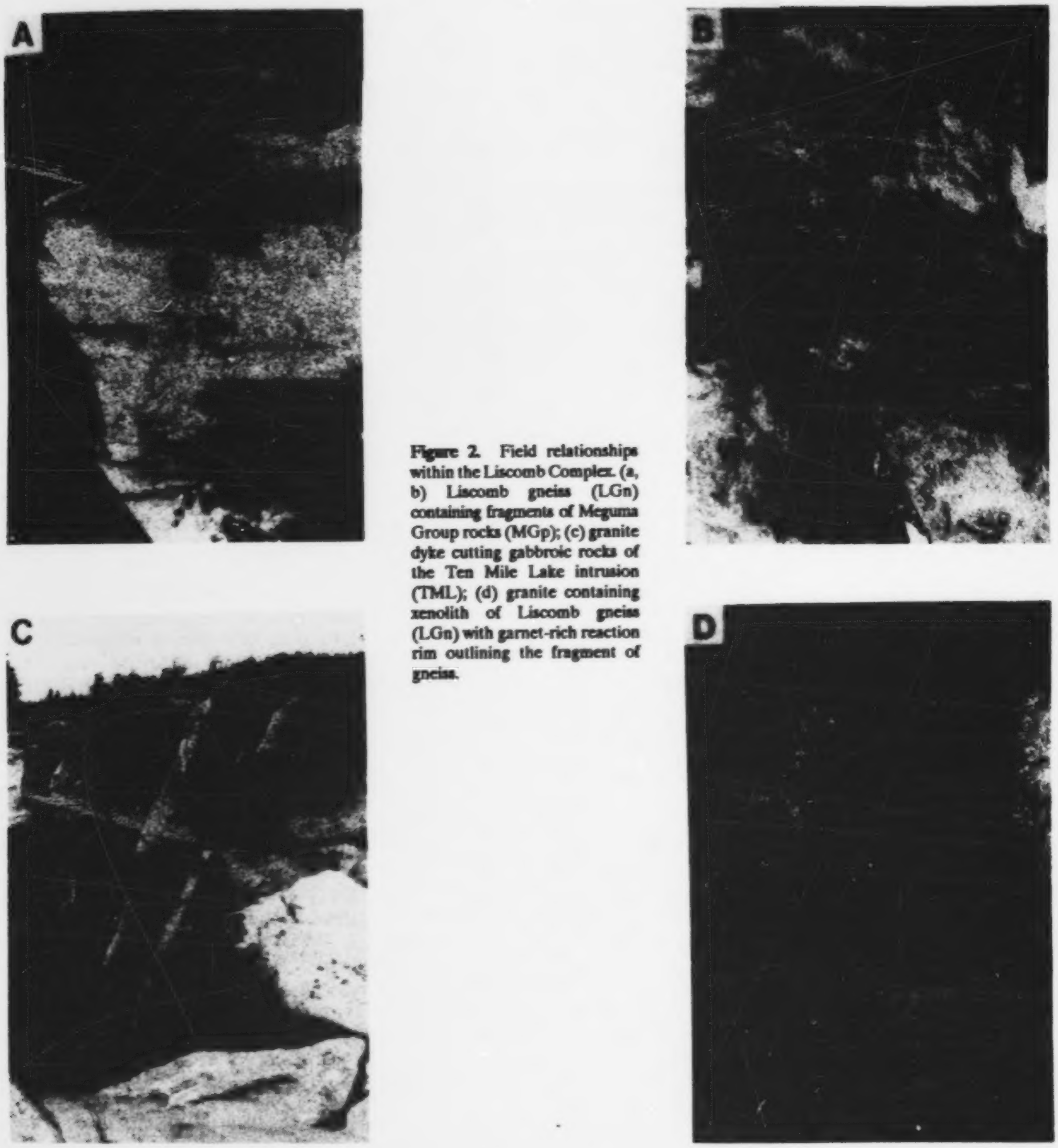

Figure 2. Field relationships within the Liscomb Complex. (a, b) Liscomb gneiss (LGn) containing fragments of Meguma Group rocks (MGp); (c) granite dyke cutting gabbroic rocks of the Ten Mile Lake intrusion (TML); (d) granite containing xenolith of Liscomb gneiss (LGn) with garnet-rich reaction rim outlining the fragment of gneiss.

MINERALOGICAL FEATURES OF THE LISCOMB GNEISS

The petrographic features and mineral chemistry of the Liscomb gneiss provide some constraints on its post-emplacement thermal history. Because of the implications such data have in terms of interpreting the results of ^{40}Ar/^{39}Ar analyses, some relevant data that constrain the thermal history of these rocks and militate against thermal overprinting due to granite/gabbro intrusion are summarized as follows:

(1) Ternary feldspars are present in quartzo-

feldspathic rocks that have thermally annealed granoblastic polygonal textures. The feldspars are characterized by very fine exsolution lamellae that reflect primary cooling following peak metamorphic conditions. Electron probe analyses of these ternary feldspars indicate metamorphic temperatures of >900°C (core) to <750°C (rim). The ternary feldspars lack the textural or chemical features expected if a low temperature (i.e. 400-500°C) thermal overprinting event had occurred.

(2) Zoning profiles in garnet from paragneiss samples indicate simple profiles with Mn-rich cores and Mg-rich rims, consistent with a simple cooling history.

(3) Garnet-biotite geothermometry indicates higher temperatures for core analyses than rim analyses.

(4) There is an absence of dissolution at grain boundaries. Grain boundary dissolution would be expected in thermally overprinted rocks.

These four features are interpreted as indicating that the Liscomb gneiss underwent a single, relatively rapid cooling history from peak metamorphic conditions which, from our additional unpublished data, are inferred to have exceeded 1000°C. There is little evidence to suggest that reheating of the gneiss occurred following this initial cooling.

GEOCHRONOLOGY OF THE LISCOMB COMPLEX

Previous Work and Relevant Radiometric Data

Previous dating in the Liscomb Complex is limited to a single conventional K-Ar biotite date from a granite in the eastern part of the complex. The age of 389 Ma (Fairbairn *et al.*, 1960; recalculated by Keppie and Smith (1978) using new decay constants) is older than the ca. 370 Ma mica ages obtained for granites in the eastern Meguma Terrane using the ^{40}Ar/^{39}Ar technique (Reynolds *et al.*, 1981; Keppie and Dallmeyer, 1987; Kontak *et al.*, 1988). Also relevant to this investigation is the recent dating of lamprophyre dykes along the eastern shore of the Meguma Terrane. Kempster *et al.* (1989) obtained ^{40}Ar/^{39}Ar hornblende ages of ca. 370 Ma for dyke rocks from two localities.

Sample Locations, Preparation and Analytical Procedures

Fourteen samples were collected from throughout the Liscomb Complex (Fig. 1) and 18 mineral separates were prepared and analyzed. Samples 1 - 4 are from granitic lithologies and represent four different intrusions. Samples 5 - 10 are from the Liscomb gneiss with localities 5 - 9 representing a detailed transect designed to examine the influence of the granitic intrusions on the thermal history of the gneissic rocks. Of particular relevance is the location of sample 5 at the gneiss -granite contact, in fact granite dykes invade the gneiss outcrop sampled in this study. The remaining sample localities (11 - 14) come from the Bog Island (11, 12) and Ten Mile Lake (13, 14) gabbroic intrusions. For the Ten Mile Lake intrusion locality 13 represents a sample of matrix material, whereas at locality 14 a cognate xenolith of mafic material representing an earlier period of higher pressure crystallization (ca. 8 kbar, Chatterjee *et al.*, 1989) was sampled. High quality mineral separates of biotite (10), muscovite (5) and amphibole (3) were prepared using conventional techniques of magnetic separation and heavy liquids. Analytical procedures employed in the ^{40}Ar/^{39}Ar analyses are fully described in Reynolds *et al.* (1987) and age plateaus have been calculated using the criteria of Fleck *et al.* (1977). Analytical data are presented as conventional age spectra, but the full data set may be obtained from the senior author upon request. Note that in some of the spectra steps are omitted due to analytical problems (e.g. loss of the gas or contamination).

^{40}Ar/^{39}Ar Results

Liscomb Granites

Age spectra for micas from granite samples are presented in Figure 3. Four of the six mineral phases analyzed have internally concordant age spectra with apparent plateau ages of 368 Ma to 372 Ma defined; the corresponding integrated ages are 368 Ma to 372 Ma (note that an incomplete age spectrum for sample LG-073 (locality 4) precludes calculation of an integrated age). In sample LG-001 both the apparent plateau and integrated ages of biotite and muscovite are essentially concordant. Both the biotite and muscovite analyses for sample LG-106 show that age gradients are present with distinct, internally discordant age spectra,

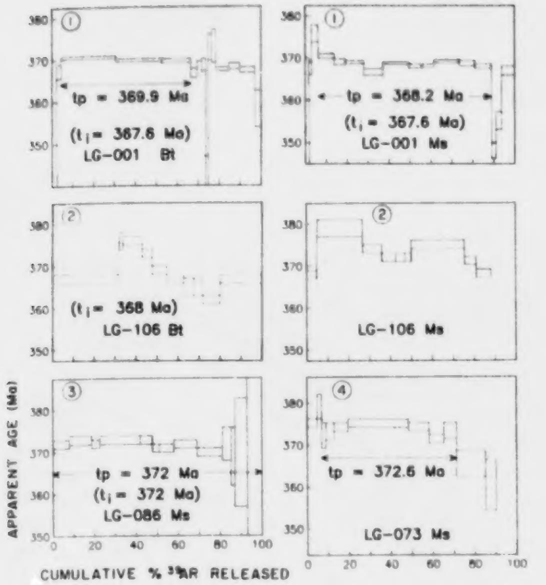

Figure 3. $^{40}Ar/^{39}Ar$ incremental release age spectra for micas from granitic rocks of the Liscomb Complex. Integrated ages in brackets (t_i) and plateau ages indicated by t_p.

contrasting with the other mica analyses from the granites. However, the integrated age for biotite (note that an integrated age cannot be calculated for the muscovite sample) is similar to the integrated ages of the micas with internally concordant age spectra.

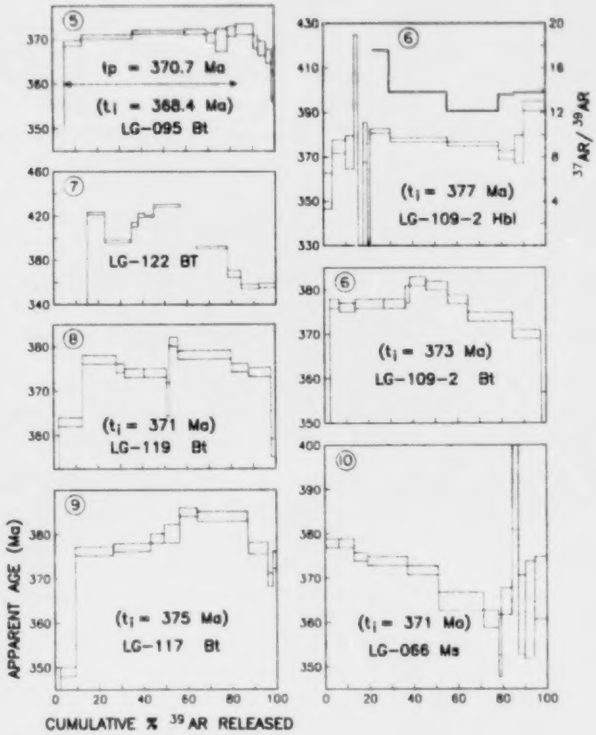

Figure 4. $^{40}Ar/^{39}Ar$ incremental release age spectra for micas and amphibole from Liscomb gneiss. Integrated ages in brackets (t_i) and plateau ages indicated by t_p.

Liscomb Gneiss

Age spectra for samples from the Liscomb gneiss are presented in Figure 4 with results from the transect (locations 5 to 9) discussed first. Biotites from localities 6, 7, 8 and 9 are characterized by internally discordant age spectra with apparent age gradients present in all the samples. However, the integrated ages (ca. 371-375 Ma) are similar to the apparent plateau ages of the micas from the granites discussed previously. In three of the four biotites analyzed (localities 6, 8, 9) relatively flat profiles with apparent ages of ca. 375-380 Ma precede the humps. Similar types of age spectra obtained for micas in which prominent humps are either preceded, succeeded or bounded by relatively flat age spectra have been reported by numerous investigators, including recent work by Muecke *et al*. (1988) and Reynolds *et al*. (1989). The latter authors found that although plateau ages were not defined, the integrated ages generally were significant. In contrast to the discordant profiles, biotite from locality 5 has a well defined, internally concordant age spectrum with an apparent plateau age of 370 Ma and an integrated age of 368 Ma. These latter ages are only slightly younger than the integrated ages for the aforementioned biotites with discordant age spectra.

A single amphibole analysis was obtained for the sample from locality 6 and it has an internally discordant age spectrum with an integrated age of 377 Ma. This age is within analytical uncertainty of the integrated age (ca. 373 Ma) for coexisting biotite from the same sample. However, for the bulk of the gas released (ca. 60%) the apparent ages fall in the narrow range of 371 Ma to 378 Ma for this sample. In addition, the $^{37}Ar/^{39}Ar$ ratio, proportional to the Ca/K ratio in the analyzed phase, is fairly uniform over this interval indicating liberation of gas from a compositionally uniform phase.

Muscovite from sample LG-066, located south of the transect just discussed, has an internally discordant profile with the initial gas fractions having apparent ages of 377 Ma and the subsequent fractions having progressively younger ages (i.e. down to ca. 360 Ma). However, the integrated age of 371 Ma is similar to the integrated ages for mica samples from the northern transect.

Liscomb Gabbros

Age spectra for samples from the gabbroic intrusions are presented in Figure 5. Age spectra for the three biotites are internally discordant with prominent humps in the middle part of the profiles. Integrated ages for the biotite samples range from 372 Ma to 385 Ma, well outside the range of analytical error (about 3-4 Ma).

Two amphiboles from the Ten Mile Lake intrusion were also analyzed. For sample LG-165A the initial 20% of gas released defines a hump with an age maximum of 390 Ma; however, the next 60% of gas released defines a plateau with an apparent age of 370 Ma which is similar to the integrated age of 371 Ma for this sample. The $^{37}Ar/^{39}Ar$ ratio for the plateau segment of the release spectrum is fairly uniform indicating gas was extracted from a compositionally uniform phase. In contrast, the initial gas released (first 20%) has a lower and more irregular ratio indicating liberation of gas from compositionally different phases. The second amphibole separate, sample LG-149-3, has an internally concordant age spectrum with an apparent plateau age of 370 Ma which is similar to the integrated age of 372 Ma for biotite from the same sample. The $^{37}Ar/^{39}Ar$ ratio suggests, however, that the gas was released from two compositionally distinct amphibole phases, initially from a relatively Ca-poor phase and subsequently from a Ca-rich phase. As Chatterjee *et al*. (1989) have pointed out, there are several stages of amphibole growth in the mafic intrusions and the variable $^{37}Ar/^{39}Ar$ ratios reflect this.

DISCUSSION

Results of the present investigation permit constraints to be imposed on the chronological and thermal evolution of the Liscomb Complex. Discussing first the granitic rocks of the Liscomb Complex, the data suggest that this suite is temporally equivalent to other peraluminous granitoid suites of the Meguma Terrane, consistent with their similar field, petrographic and chemical characteristics. In addition, there is apparently no resolvable difference between the early, relatively primitive granitoid phases and the later, more evolved leucogranite phases. As with the other granitoid suites (e.g. South Mountain Batholith), the concordancy of biotite and muscovite dates indicates rapid post-crystallization cooling of the granitoid bodies below the blocking temperatures of the mica phases (300-350°C).

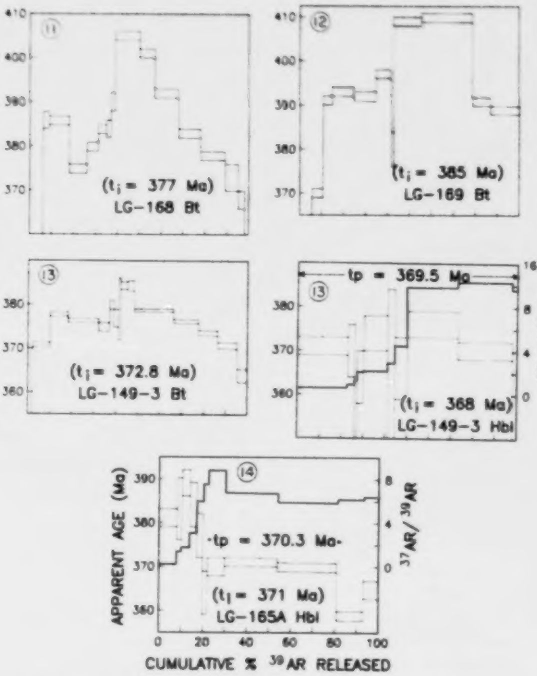

Figure 5. $^{40}Ar/^{39}Ar$ incremental release age spectra for micas and amphiboles from gabbroic rocks of the Liscomb Complex. Integrated ages in brackets (t_i) and plateau ages indicated by t_p.

Data for the Liscomb gneiss do not define plateau ages (except one sample discussed below) and for this reason interpretations are not as tightly constrained as compared to the granites. However, if the integrated ages of the biotites are significant then cooling of the gneiss through the blocking temperature of this mineral (ca. 300°C) occurred at ca. 373 Ma. If one is cautious in interpreting the age spectrum obtained for the amphibole (locality 6) as perhaps indicating a cooling through its blocking temperature (ca. 500° C) at ca. 375 Ma, then this would imply rapid cooling of the gneiss terrain after its emplacement. Considering the departure of the age spectra from profiles expected from simple diffusion if resetting related to emplacement of the granites had occurred, it is tentatively suggested that the ages obtained represent the time of emplacement of the Liscomb gneiss.

The single concordant age spectrum obtained for the Liscomb gneiss samples is for a locality immediately adjacent to the granites. In light of (1) the marked contrast of the age spectrum relative to those obtained for gneiss samples away from the granite, (2) the coincidence of the plateau age with plateau ages for micas from the granites, and (3) the presence of granite dykes in the same outcrop of gneiss that was sampled, it seems likely that the biotite was outgassed as a result of granite intrusion.

The amphibole data from the Ten Mile Lake intrusion indicate emplacement at ca. 370 Ma. The integrated age (ca. 372 Ma) of a biotite (sample LG-149-3) coexisting with one of the amphiboles indicates rapid post-crystallization cooling of the mafic rocks through the blocking temperatures of these phases (500° and 300°C, respectively). The anomalously older integrated ages for the biotites from the Bog Island intrusion (377 Ma and 385 Ma) may indicate the presence of some excess argon.

Collectively the geochronological data indicate that the Liscomb Complex formed ca. 370 Ma ago. Although field relationships indicate the sequence gneiss, gabbro then granite, the present study cannot resolve any significant time difference separating these geologically separate events. In addition, the data indicate that the area cooled rapidly after 370 Ma because of the general concordancy of the amphibole, muscovite and biotite ages. These finds are consistent with the conclusions of Kontak *et al*. (1988, 1989a, 1989b; and unpublished data of Kontak) for the Beaver Dam area immediately south of the Liscomb Complex where ^{40}Ar/^{39}Ar analyses of amphibole, muscovite, biotite and K-feldspar indicate concordant ages at 370 Ma.

Finally, this study confirms the findings of Kempster *et al*. (1989) in which they documented for the first time the temporal equivalence of mafic and felsic magmatism within the Meguma Terrane. Our data support the 370 Ma age these authors obtained for mafic magmatism within the Meguma Terrane.

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GOLD ANOMALIES IN THE -230 MESH FRACTION OF BULK STREAM SEDIMENT SAMPLES FROM NORTHERN NOVA SCOTIA[1]

R. F. Mills

INTRODUCTION

A geochemical survey of stream sediments and stream waters was carried out across northern mainland Nova Scotia and Cape Breton Island in 1986 and 1987 (Mills, 1989). Approximately 3300 stream sediment samples, including duplicates, were analyzed for 30 elements in the coarse (-60+230 mesh) heavy mineral separate fraction, and for 16 elements in the bulk fine fraction (-230 mesh). Some of the original gold analyses were supplemented with later fire assay analyses for gold. The primary objective of the survey was to provide a database for gold exploration in the relatively unexplored northern part of the Province using a technique specifically designed to retain gold.

The data were released in November 1989 as Nova Scotia Department of Mines and Energy Open File Report 89-007 (Mills, 1989). The report consists of analytical tables for the two fractions of stream sediment (-60+230 and -230), analytical tables for water analyzed in the program, tables of field data and an accompanying report. Due to the regional nature of the data release, conclusions and review of anomalies were kept brief. This paper presents a further discussion of the gold anomalies found in the -230 mesh fraction of samples collected during the survey.

Previous stream sediment sampling in this region of Nova Scotia was carried out by Rogers and MacDonald in 1982, with smaller samples being collected and analyzed. Their work produced numerous departmental Open File Maps on the geochemistry of northern Nova Scotia at a 1:50 000 scale (see Lyttle *et al.*, 1986, and Lyttle and Gillespie-Wood, 1987, for complete listing under Rogers, P. J. or MacDonald, M. A.).

METHODS

Sample Collection and Preparation

The morphology of northern Nova Scotia favours high energy stream environments which provide good sample media for a regional survey. High energy environments have been noted to produce the best conditions for the concentration of heavier elements in streams (Fletcher and Day, 1988). Bulk (3-5 kg) stream sediment samples were passed through an 18 mesh nylon field screen and collected in a plastic pan along with all of the water used during sieving (Mills, 1988). The -18 mesh sample and water were poured into a 3 ml polythene bag. This field sampling procedure minimized loss of fine gold by saving the water used during sieving. Boyle (1979) has shown that water used during sieving may carry away fine gold.

Air was removed from the bags after the samples were placed on a table for at least 48 hours to allow the fine gold to settle. The excess water was then siphoned out of the bags and samples were packed for transport to the sample preparation laboratory. Each sample was sieved through 60 and 230 mesh screens. A heavy mineral separation was carried out on the -60+230 mesh fraction and the resulting heavy mineral concentrate was analyzed by induced neutron activation analyses and X-ray fluorescence. The -230 mesh fraction was analyzed by induced neutron activation analysis and plasma atomic emission spectroscopy. These methods of bulk field collection and analysis of more than one fraction of stream sediment are well suited to regional exploration for gold in areas where the type and mode of gold occurrence are unknown (Reimann, 1988).

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[1] Funded by the Geological Survey of Canada under the Canada - Nova Scotia Mineral Development Agreement

Analytical Methods

Two size fractions from each stream sediment sample were analyzed. The -230 mesh (fine) fraction was analyzed for a suite of precious and base metals, and their granophile, siderophile and chalcophile indicators. Heavy minerals from the -60+230 mesh fraction were separated using methyl iodide diluted with acetone to a specific gravity of 2.95 and were analyzed for a similar set of elements (Mills, 1988).

The laboratory procedure for the 1986 field samples used tetrabromoethane as the separation medium. In 1987 the laboratory procedure used methyl iodide that was diluted to the same specific gravity as tetrabromoethane (S.G. 2.95) with acetone so that results from both years would be comparable. The preferred use of methyl iodide was determined from a pilot study performed in 1987 to determine which separation medium is best suited to extracting heavy minerals from stream sediments in Nova Scotia (Lombard and Mills, 1987).

Quality Control Procedures

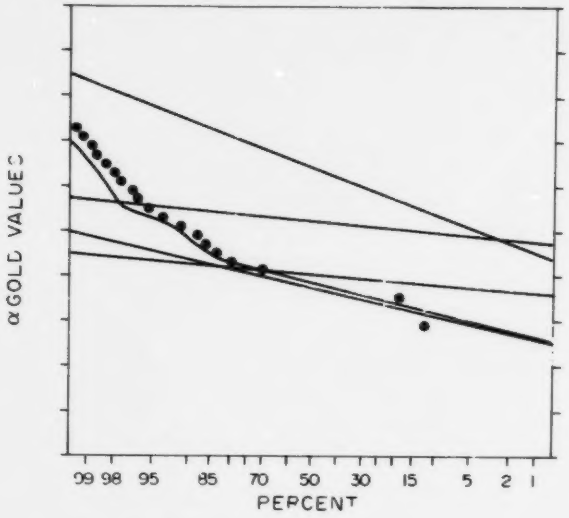
The vials of samples were grouped into analytical batches consisting of 20 consecutively numbered samples. Included in every batch were two randomly chosen field duplicates, an analytical duplicate and a standard. The field duplicates determine field site variation, the analytical duplicates measure analytical precision and the standard measures the accuracy of the laboratory.

Data Presentation

The database consists of several parts. These are: (1) the analyses file from the stream sediment heavy mineral concentrate (for 1986 and 1987), (2) the fine (-230 mesh) fraction analyses file (for 1986 and 1987), (3) the stream water analyses files (for 1986 and 1987), (4) a text file including sample site information and UTM location co-ordinates (for 1986 and 1987) and (5) the 1986 fire assay file. Each data subset was sorted into 1:50 000 map sheets. This is useful in delineating exploration targets on a scale compatible to the system of staking claims in Nova Scotia. This format will also enable later workers to easily use the data for statistical treatment such as catchment basin analysis and X Y plots.

Sample locations for the fine fraction gold analyses were digitized and presented in three 1:250 000 scale map sheets. Data were organized into either Map No. 1, the Cumberland, Colchester and Pictou Counties sheet (Cobequid Highlands and surrounding area); Map No. 2, the Antigonish, Colchester, Guysborough and Pictou Counties sheet (Antigonish Highlands and surrounding area); or Map No. 3 covering Cape Breton Island.

Inspection levels (Garrett, 1989) for fine fraction gold were identified using an interactive computer program designed for geochemical exploration data (PPLOT). The software produces probability plots and histograms (Fig. 1) from log-transformed data. The combined contour and symbol maps were plotted using percentile units.



LOGARITHMIC VALUES

Variable = Au ppb
Unit =
N = 2728
N CI = 35

POPULATIONS

Pop.	Mean	Std. Dev	%
1	0.1759	0.2715	80.7
2	0.3435	0.0997	9.8
3	0.9996	0.1146	7.0
4	1.6508	0.4474	2.5

Figure 1. Representation of a probability plot produced using PPLOT software.

To generate the contours, the randomly positioned samples were gridded to create uniform grid cells. At each grid intersection the software used a circular search radius to determine which primary data points to use in computing a value displayed at the centre of the circle (Teed, personal communication, 1989). These values were then contoured resulting in a trend surface over which the individual sample symbols were superimposed.

GOLD RESULTS

The dataset for northern Nova Scotia has contrast between background and anomalous gold values of at least 11.5 ppb. Anomaly significance increases with contrast strength. Several anomalous patterns correspond to known structural trends, and also to dispersion patterns in the primary and secondary environments as a result of mechanical and hydromorphic dispersion from known sources.

Most anomalous gold values come from samples taken in highland terrain. In Cape Breton Island all areas of grouped anomalies above the 95th percentile occur in the highlands (Fig. 2). Several grouped anomalies outline areas where known mineral deposits and large shear zones occur.

Cape Breton Island

An extensive northeast-trending series of anomalies exists south of Cape Breton Highlands National Park (Fig. 2), and is currently under investigation. Part of this trend of anomalies extends into Cape Breton Highlands National Park. These anomalies are underlain by some of the oldest rocks in the Province, including the Precambrian George River Group. The rocks consist of highly metamorphosed remnants of Precambrian sedimentary and volcanic rocks. The area of the anomalies is traversed by extensive shear zones. These areas where George River Group rocks are extensively sheared include anomalies at Ingonish, North River and Wreck Cove.

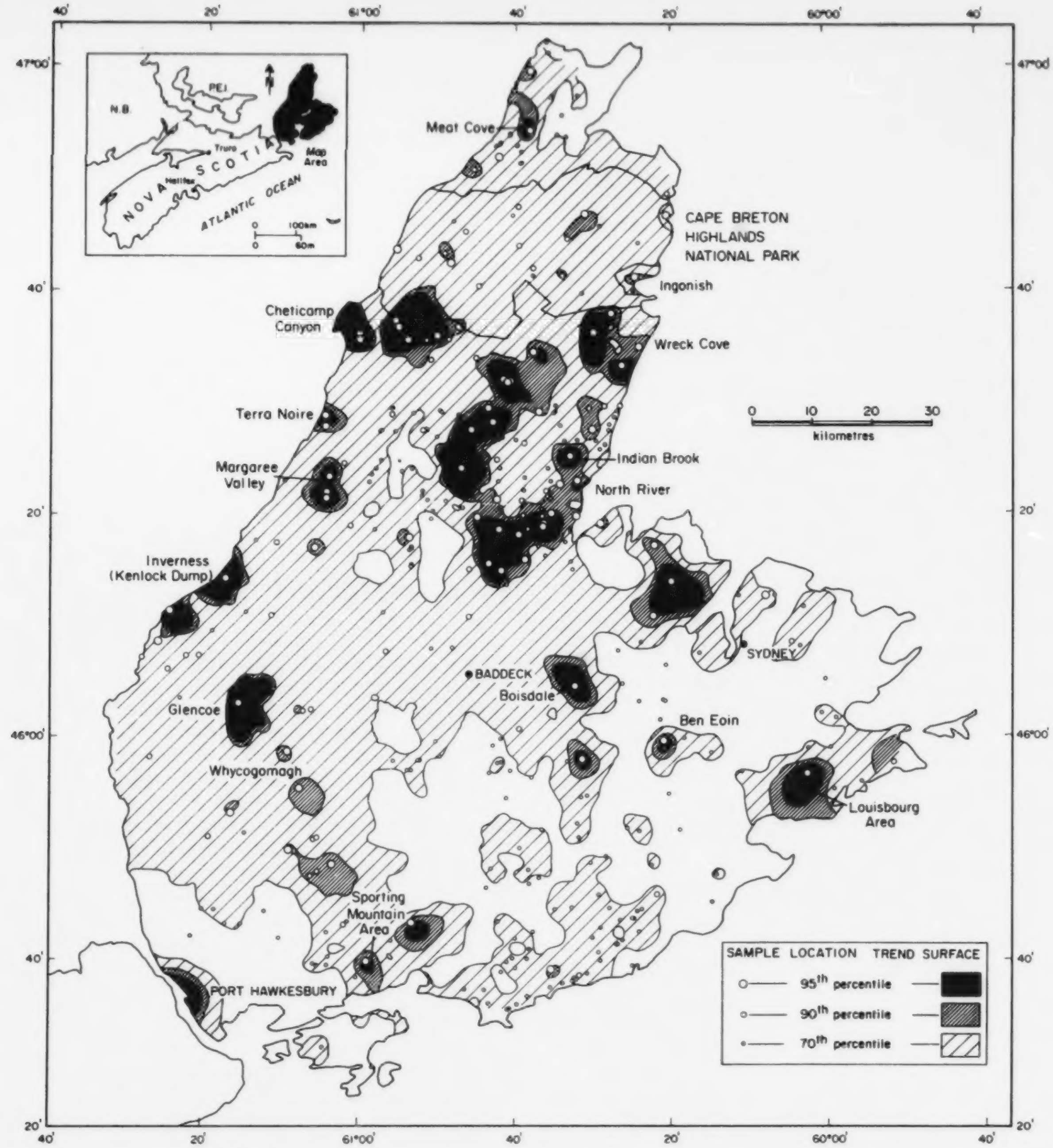
Anomalies at Meat Cove, Whycocomagh, Glencoe and Boisdale may signify underlying skarns of the George River Group (Chatterjee, 1980; Barr and Setter, 1984), though the mineralogies are varied. Meat Cove is a subeconomic deposit with major Zn and minor Cu and Pb; the deposit has a pronounced geochemical signature (Rogers and MacDonald, 1984, 1987). At Whycocomagh and Glencoe the occurrences include Cu, Zn and W. The Boisdale occurrence is predominantly a copper-rich skarn in George River Group carbonates (Northcote *et al.*, 1989). The anomalies on Sporting Mountain are hosted in a volcanic chamber of the late Precambrian Fourchu Group (Sexton, 1986). The area has been examined as a possible source of copper but the mineralization is considered to be sub-economic. The Louisbourg area hosts several anomalies. Polymetallic mineralization has been documented in this area and is related to a contact metamorphic aureole (Macdonald, 1989).

Another locality that has long been of economic interest is the Cheticamp Canyon area, and a significant anomalous zone has been outlined there by this survey. The anomalous zone is polymetallic in nature, related to massive sulphide mineralization in highly metamorphosed schists (Plint *et al.*, 1986). The zone reflects the significant massive stratabound mineralization that occurs there. The main host rocks are biotite schist for Cu-Pb-Zn (Ag, Au, Bi, As) mineralization, and hornblende schist for Zn-Cu (Ag, Au) mineralization (Chatterjee, 1980). The mode of sulphide emplacement involves a complex relationship between granitic magmatism, metamorphism and zoned alteration. Other interesting anomalies exist in the Margaree Valley area, Ben Eoin and Terra Noire.

Antigonish Highlands

In the Antigonish Highlands anomalies occur at Beaver Mountain and near the coast at Knoydart (Fig. 3). Two major fault systems lie close to both anomalies and may host the source. There are also weaker anomalies north of Antigonish and throughout the highlands. The contoured trend surface for the Cross Roads Ohio area includes multi-element anomalies at the Lochaber Lake prospect and west of the College Grant prospect. Both of these areas host significant copper sulphides. The Lochaber Lake deposit displays a large, well defined base metal anomaly hosted in finely stratified calcareous rocks of Devonian(?) age. At College Grant mineralization occurs within a hydrothermally altered mafic pluton. This geochemical signature is also known to exist in the local tills (R. R. Stea, personal communication, 1989). The source for this signature is not known at this time. Rogers (1989) noted that a strong biogeochemical gold signature in the same area could be in part due to glacial smearing southeastward from the Cross Roads Ohio area. Rogers (1989) also speculated that possible structural trends in basement rocks could control the source(s).

Another notable gold anomaly exists near Guysborough close to Havendale (Turner and Stea, 1986). This anomaly also corresponds to anomalies of Cu, Pb, Zn, Co, Mn, Mg and As and is in close proximity to the Chedabucto Fault Zone. Other anomalies appear in the Mulgrave area, Grosvenor,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CAPE BRETON HIGHLANDS NATIONAL PARK
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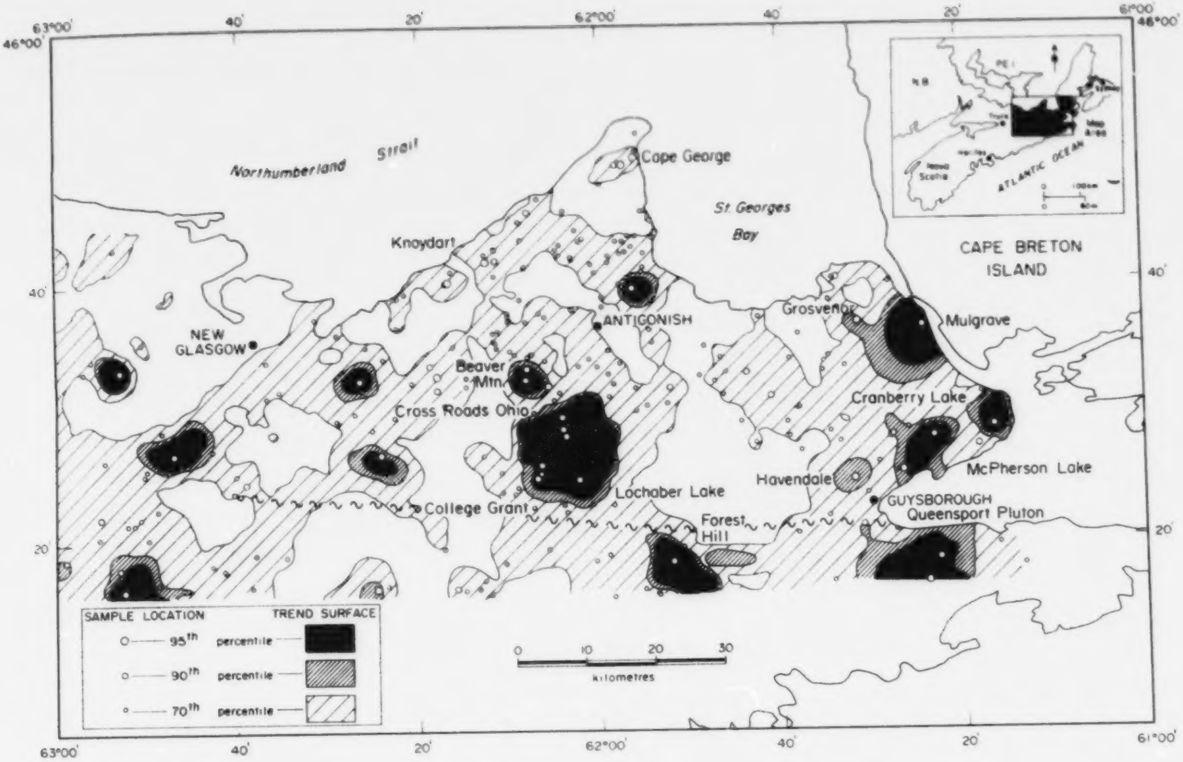
Indian Brook
Margaree Valley
North River
Inverness (Kenlock Dump)
SYDNEY
BADDECK
Boisdale
Glencoe
Ben Eoin
Whycogomagh
Louisbourg Area
Sporting Mountain Area
PORT HAWKESBURY
SAMPLE LOCATION
TREND SURFACE
95th percentile
90th percentile
70th percentile

Figure 2. Fine fraction (-230 mesh) gold plot for Cape Breton Island.

Cranberry Lake and McPherson Lake. South of the Antigonish Highlands the Queensport Pluton vicinity reflects higher than background values. There is also a pronounced gold signature at Forest Hill, a former gold producer.

Cobequid Highlands

In the Cobequid Highlands (Fig. 4) there are restricted anomalies north and northeast of Truro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ANTIGONISH
NEW GLASGOW
Beaver Mtn.
Cross Roads Ohio
College Grant
Lochaber Lake
Forest Hill
Grosvenor
Mulgrave
Cranberry Lake
McPherson Lake
Havendale
GUYSBOROUGH
Queensport Pluton
CAPE BRETON ISLAND
ATLANTIC OCEAN
SAMPLE LOCATION
TREND SURFACE
95th percentile
90th percentile
70th percentile
0
10
20
30
kilometres

Figure 3. Fine fraction (-230 mesh) gold plot for the Antigonish Highlands region.

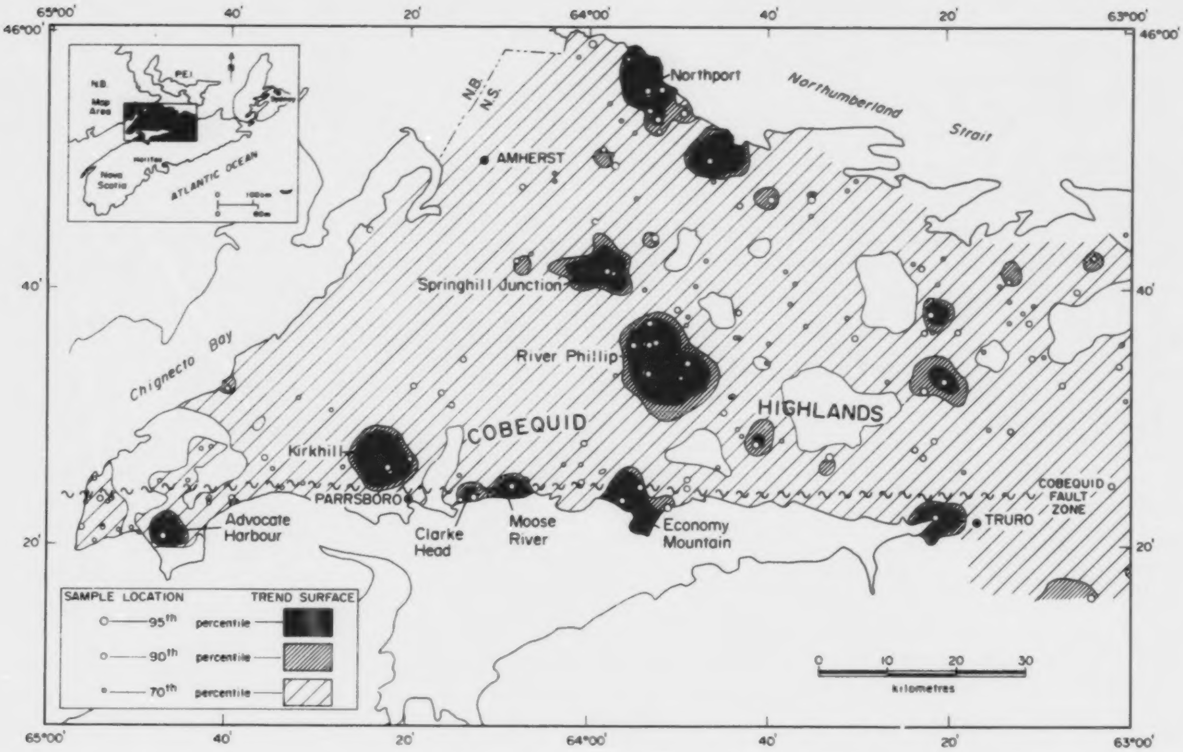
that have not been well documented, but have been encountered during past exploration (Miller, personal communication, 1988). Several well documented showings are marked by anomalies in the Cobequid Highlands. The River Philip area has an extensive, strong, well defined gold signature. This and a similar anomaly at Springhill Junction overlie Carboniferous conglomerates and may represent paleoplacer concentrations. There are anomalies associated with previously known, structurally controlled, polymetallic showings along the Cobequid Fault Zone, the western extension of the Chedabucto Fault, at Economy Mountain and Moose River, and near Clarke Head, Kirkhill and Advocate Harbour.

Suspect Anomalies

One of the anomalies within the dataset is believed to be the result of man-made contamination. At Inverness a strong (95th percentile) anomalous signature occurs in the vicinity of the Kenloch garbage dump (Fig. 2). However, the possibility that this is coincidental, and that the anomaly is real, should not be ruled out. The geochemical remnants of old gold workings can also influence analysis. Metals from tailings or gangue can introduce contamination, especially in the fine fraction, if they find their way into the secondary environment. Such a case may exist in the Northport area (Fig. 4). Rumors of a 'boot-leg' (uncertified) mill in the area before the turn of the century and mercury in the local beach sand (R. J. Ryan, personal communication, 1989) support this idea, though the anomaly should not be ruled out as a possible paleoplacer, such as the anomalies at River Philip and Springhill Junction. Whatever the case, there is a strong (95th percentile) anomaly in the vicinity, in Carboniferous basin fill rocks not commonly auriferous in Nova Scotia.

CONCLUSIONS

The primary objective of the survey was to build a coherent geochemical database in order to benefit industry with a regional, reconnaissance survey specifically designed for the retention of gold and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Halifax
Nova Scotia
ATLANTIC OCEAN
N.B.
N.S.
Northport
Northumberland Strait
AMHERST
Springhill Junction
River Phillip
Chignecto Bay
COBEQUID
HIGHLANDS
Kirkhill
PARRSBORO
Advocate Harbour
Clarke Head
Moose River
Economy Mountain
TRURO
COBEQUID FAULT ZONE
SAMPLE LOCATION
TREND SURFACE
95th percentile
90th percentile
70th percentile
0
10
20
30
kilometres

Figure 4. Fine fraction (-230 mesh) gold plot for the Cobequid Highlands region.

analysis of its concentration. This objective was met with release of the geochemical report and the response of industry to the survey. The separation of populations in the database differentiates regional background from higher local trends. The distribution of gold values reflects geochemical signatures of known metal distribution patterns as well as outlining anomalous areas that require follow-up work. The data presentation allows high local values to be superimposed on regional trend surfaces with symbols that outline statistically significant geochemical signatures. This reflects a successful method for attaining the objective of the survey.

Industry response to the database provided a good indication of the interest in this project. Within hours of the release of Open File Report 89-007, 565 claims were staked in Nova Scotia. Final tally of claims staked on the basis of the report is over 1000. This represents a financial commitment from industry to the Province in terms of assessment of claims of over $200,000 for the first year. Obviously, some of the claims will be retained for further work and possible development and it is not unrealistic to assume expenditures into the millions of dollars. This is a significant benefit to the Province of Nova Scotia in terms of employment and economic growth.

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RECENT ADVANCES IN THE GEOLOGY OF THE SOUTH MOUNTAIN BATHOLITH: ANATOMY AND ORIGIN OF A BATHOLITH[1]

M. A. MacDonald, M. C. Corey, L. J. Ham,
R. J. Horne and A. K. Chatterjee

Recent detailed geological mapping of the South Mountain Batholith (SMB) of southwestern Nova Scotia has delineated 260 granitoid bodies which have been assigned to 49 map units. Map units have been grouped into eight rock types that, in order of decreasing mafic mineral content (biotite, cordierite, garnet), include: biotite granodiorite (9.6% of the SMB); mafic porphyry (0.04%); biotite monzogranite (52.2%); muscovite-biotite monzogranite (8.9%); coarse grained leucomonzogranite (21.1%); polyphase intrusive suite (0.7%); fine grained leucomonzogranite (6.8%); muscovite leucogranite (0.75). Muscovite is present in all rocks and increases from trace in granodiorite to >20% in some leucogranites. Biotite, with accessory zircon, monazite, apatite, ilmenite±rutile±xenotime±allanite, decreases from >25% in some granodiorites to 0% in most leucogranites. Cordierite is present in trace amounts in most rocks and may constitute up to 5% of the mode.

The mapping has delineated at least 13 plutons within the SMB. These plutons can be divided into biotite-bearing (granodiorite-monzogranite) and muscovite-biotite-bearing (monzogranite-leucomonzogranite-leucogranite±granodiorite) compositional types. Plutons may be lithologically composite, consisting of several rock types, or uniform, comprising a single rock type. Recent geochronological data (^{40}Ar/^{39}Ar, Pb-Pb) on mica and whole rock suites, representing the entire compositional range, indicate that the plutons were emplaced circa 370 Ma.

Geochemical analyses of the eastern SMB indicate that all rocks are peraluminous (A/CNK 1.13-1.29) with low Ca (0.41-2.87%) and high SiO_2 (67.10-73.90%) contents. Most major and trace elements display smooth variation trends attributable to the removal of biotite and included accessories, plagioclase and alkali feldspar by fractional crystallization. Most plutons display compositional zoning (normal and/or reverse) defined by systematic variations in mineralogy and geochemistry. These variations result from pluton-scale fractional crystallization. Each pluton represents one or more magmas that rose, coalesced with adjacent plutons and fractionated in situ.

Oxygen isotope data (9-12‰) and ^{87}Sr/^{86}Sr (0.7080-0.7100 except >0.720 for the Davis Lake Pluton) are consistent with derivation of the SMB magma via partial melting of metasedimentary and altered volcanic rocks. The aluminous and mafic granulite xenoliths from Tangier are probably a suitable source material for the SMB magma. This requires that the SMB magma was generated during the collision of the Meguma Zone.

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[1] Paper presented at the Atlantic Geoscience Society Colloquium on Current Research in the Atlantic Provinces, Wolfville, Nova Scotia, February 9-10, 1990

GEOLOGY AND MINERALIZATION ASSOCIATED WITH THE TOBEATIC LAKE SHEAR ZONE, SOUTHWESTERN NOVA SCOTIA[1]

M. C. Corey, R. J. Horne and P. K. Smith

The Tobeatic Lake Shear Zone (TLSZ) is situated approximately 45 km NE of Shelburne along the southern South Mountain Batholith (SMB)/Meguma Group contact. The TLSZ is a NE (060°) trending, brittle-ductile shear zone that is exposed intermittently for approximately 8 km. The TLSZ is similar in orientation and style of deformation to the Rushmere Lake shear zone (RLSZ) situated approximately 25 km to the southwest. Both shear zones are considered part of the regional Tobeatic Fault Zone.

Intense brittle deformation within the TLSZ is reflected by a $\leq$100 m wide quartz-breccia zone. The breccia zone is composed of altered (hematized, kaolinized, silicified) leucomonzogranite, metasediment, ultramylonite and microbreccia clasts. These clasts probably represent previously deformed (brittle, ductile) rock refragmented by intense hydrothermal activity associated with extensive multi-stage quartz veining. Shear-related effects (quartz veining, c-s fabrics) are observed in the leucomonzogranite wall rocks up to 1 km away from the quartz-breccia zone.

Mineralization associated with the quartz-breccia zone includes: fine- to coarse-disseminations of galena-sphalerite-barite and/or chalcopyrite-arsenopyrite-pyrite within quartz-veins and vuggy quartz-breccia boulders. Petrographic observations indicate that there were several stages of mineral deposition. Analysis of grab samples of mineralized quartz-breccia boulders from along the TLSZ returned up to 10% combined Pb-Zn and 2% Ba. While this type of mineralization is unique to the SMB, similar mineralization (excluding barite) occurs within the Musquodoboit Batholith at the Dunbrack prospect. A compilation of mineral exploration assessment reports and the results of recent geological mapping in the Tobeatic Lake area indicate that approximately 6 km of the TLSZ has potential for hosting significant Pb-Zn-Ba mineralization. Heavy mineral concentrate samples obtained during mineral exploration indicate that the TLSZ may also be a good target for Sn-W mineralization. The presence of Pb-Zn heavy mineral concentrate anomalies and mineralized quartz-breccia boulders up-ice of the TLSZ suggests that other areas of mineralization exist, possibly within associated shear zones. In addition, many mineralized samples contain significant amounts of Au, with concentrations ranging from 100-2000 ppb.

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[1] Paper presented at the Atlantic Geoscience Society Colloquium on Current Research in the Atlantic Provinces, Wolfville, Nova Scotia, February 9-10, 1990

PETROGRAPHIC AND GEOCHEMICAL EVIDENCE FOR A HYPOGENE ORIGIN OF GRANITE-HOSTED, VEIN-TYPE Mn MINERALIZATION AT THE NEW ROSS Mn MINES, LUNENBURG COUNTY, NOVA SCOTIA[1]

G. A. O'Reilly

The abandoned New Ross Mn mines are hosted in megacrystic biotite monzogranite of the South Mountain Batholith (SMB) 10 km north of New Ross, Lunenburg County. Past workers disagree as to whether the deposits are of supergene or hypogene origin. Recent deep diamond-drilling and geological mapping at the Dean and Chapter mine have provided new data that support a hypogene origin for the deposits. The SMB in this area consists mostly of coarse grained megacrystic biotite monozogranite. A swarm of small, elongate leucomonzogranite plutons both intrude and are in fault contact with the monzogranite to the north and west of the Dean and Chapter mine and at depth below the past mine workings. These plutons occur elongate parallel to a series of persistent, northeast-trending topographic linears which traverse this region of the SMB and, in most cases, represent faults and/or shear zones. This spatial association suggests these structures played a role in the localization of the plutons. Brecciation and hydrothermal alteration of the leucomonzogranites indicate movement and hydrothermal activity continued on the faults after final crystallization of the plutons.

Several types of hydrothermal alteration are well-developed in the mineralized zones at the mines and along several other of the northeast-trending structures in this region. The diamond-drilling shows that although the Mn mineralization is absent at depth, the shear zone and hydrothermal alteration persist to at least 452 m (1482 ft) below the mine workings. Low temperature, postmagmatic hematization and kaolinization are best developed within the main ore-bearing zones from surface to a depth of about 150 m (492 ft). With increasing depth, the amount of kaolinization decreases but hematization remains important. Desilicification (episyenitization) accompanies hematization at several locales both in the megacrystic monzogranite and the leucomonzogranite intrusions. The desilicification is developed to the point that no free quartz remains in the rock. Higher temperature alterations such as silicification, greisenization, K-feldspathization and albitization occur associated with emplacement of the leucomonzogranite. The silicification occurs as total replacement of the rock and grades through greisenized selvages into fresh leucomonzogranite or monzogranite.

The activity of phosphate during the alteration sequences is of particular importance. At depth below the mine, P_2O_5 enrichment occurs in the higher temperature silicified, greisenized, K-feldspathized and albitized rocks (up to 5.20 wt.% P_2O_5). The importance of phosphate in the system continued into the lower temperature alterations and also crystallized as apatite intergrown with the Mn- and Fe-oxides in the mineralized zones (up to 9.95 wt.% P_2O_5). The textural relations and geochemical signatures indicate the entire alteration sequence and the mineralization comprise an evolving hydrothermal system developed from upward migrating hydrothermal fluids. These processes operated over much of this region of the SMB and suggest a high potential for as yet undiscovered deposits.

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EMPLACEMENT OF THE SOUTH MOUNTAIN BATHOLITH: STRUCTURAL AND INTRUSIVE CONSIDERATIONS[1]

R. J. Horne, M. C. Corey, L. J. Ham and M. A. MacDonald

The ca. 370 Ma South Mountain Batholith (SMB) is a polyintrusive complex emplaced into Meguma Group metasediments during widespread Acadian magmatism in the Meguma Terrane. The duration of intrusion was short (i.e. 1-3 Ma) with batholith emplacement representing a single event. Emplacement was advanced by two principal processes, diapirism and stoping.

Little is known of the emplacement mechanism below the present level of exposure, however it is probable that diapirism was the dominant process at deeper levels with stoping becoming more important in the final stages of emplacement. Diapiric ascent occurred along a major, long-lived, crustal-scale structure now represented by a series of regional NE-trending faults which transect the SMB and country rocks; the Tobeatic and East Kemptville - East Dalhousie Fault Zones. Late-stage intrusions localized along these faults indicate activation of these structures at the time of emplacement.

Evidence of stoping occurring at contacts, an abundance of xenoliths and a general lack of deformation of regional Acadian structures in the country rocks imply stoping was the dominant mode of emplacement at the present level of exposure. Linear NE- and NW-trending granite/country rock and granite/granite contacts demonstrate stoping was influenced by coincident structures in the country rocks (pre-granite structures) and early phases of the batholiths (syn-granite structures). These structures are represented by the dominant regional joint trends and faults in the SMB and by joints and faults in the country rocks, which together constitute the dominant structural pattern in the Meguma Zone.

The SMB is polyintrusive, consisting of numerous discrete intrusions which are petrographically and geochemically distinct from one another. This complex intrusive character is interpreted to reflect intrusion of numerous independent intrusions rather than differentiation of a single, large magma chamber.

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[1] Paper presented at the Atlantic Geoscience Society Colloquium on Current Research in the Atlantic Provinces, Wolfville, Nova Scotia, February 9-10, 1990

USE OF NONPARAMETRIC RANKING STATISTICS TO IDENTIFY MAGMATIC AND POST-MAGMATIC PROCESSES IN THE EASTERN SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA, CANADA[1]

M. A. MacDonald and D. B. Clarke[2]

The South Mountain Batholith (SMB) is a large (≈10,000 km^2), Devonian, post-tectonic, peraluminous granitoid complex that cuts mainly flyschoid metasedimentary rocks of the Cambro-Ordovician Meguma Group of southwestern Nova Scotia. Many studies have shown that fractional crystallization controls chemical variation in most of the SMB (see Clarke and Muecke, 1985, for a review), and also that variable degrees of post-magmatic hydrothermal alteration (e.g. greisenization, albitization, etc.) modified the compositions produced by magmatic processes (Clarke and Chatterjee, 1988). Recent detailed mapping, followed by extensive petrographic and analytical work, provides a large geochemical database (MacDonald and Horne, 1988; Ham et al., 1989). This paper applies the non-parametric Spearman rank correlation coefficients (SRCC) to a selected group of the new chemical analyses to quantify the degree of inter-element correlation in a single pluton (the Halifax Pluton, HP) showing a range of compositions from granodiorite to monzogranite, to quantify the degree of inter-element correlation in two suites of compositionally restricted leucogranites, and to assess the reasons for these correlations in terms of magmatic and post-magmatic processes. We also examine the influences of other factors on the inter-element correlations.

We have selected three subsets of samples from the SMB. The first suite consists of 77 granodiorite and monzogranite samples representing the compositional variation in the HP, a zoned, cordierite-bearing, plutonic complex at the eastern end of the SMB (MacDonald and Horne, 1988). Our second suite consists of 18 samples of leucogranite (<2% biotite±cordierite±garnet) occurring as zones (generally <100 m^2) within fine-grained monzogranitic units and are, therefore, termed associated leucogranites (AL). This leucogranite type has low concentrations of incompatible elements (e.g. F, Rb, Ta, Sn), rarely contains accessory andalusite, topaz or fluorite, and has more anhedral replacement muscovite than euhedral (primary?) muscovite. Our third suite consists of 34 leucogranites that occur as discrete bodies (<1-5 km^2) that intrude most other rock types in the SMB and are termed non-associated leucogranite (NL). This type of leucogranite has the highest concentrations of incompatible elements, contains accessory andalusite, topaz and fluorite and has more euhedral (primary?) muscovite than anhedral (replacement) muscovite.

Spearman rank correlation coefficients were calculated for each of the three data sets (HP, AL, NL) (Fig. 1). The SRCCs that are moderate to strong in the HP data set, but insignificant in the leucogranites (AL, NL), primarily involve pairs of compatible elements that reside primarily in the major mineral phases plagioclase (CaO, Sr), alkali feldspar (Ba, Rb) and biotite (Sc, V, Fe_2O_3, TiO_2, MgO) and the accessory minerals zircon (Zr, Th, Hf), monazite (La, Th) and xenotime (Y). Bivariate plots for four representative SRCCs (Ba-Sr, Ba-Zr, V-Sc and Sc-Sr) are presented in Figure 2. The strength of the SRCCs for each of the three data sets is also plotted. Either the NL samples never had significant correlation coefficients involving these elements, or the SRCCs were degraded by a subsequent process. In all cases the AL have intermediate SRCCs between the strongly significant HP data and non-significant NL data. Conversely, the SRCCs that are moderate to strong in the AL and NL , but insignificant in the HP, primarily involve elements that behave incompatibly (Rb, F, Sn, W, Ta, Li), i.e. those elements that tend to concentrate in the residual melt and/or volatile-rich fluid phase. Bivariate plots and the SRCCs of four representative element pairs (Rb-F, Sn-F, Na_2O-K_2O, P_2O_5-Al_2O_3) are shown in Figure 3. Either the HP samples never had significant correlation coefficients involving these elements, or the SRCCs were degraded by a subsequent process. In all cases the strength of the SRCCs in the AL data is intermediate between the HP and NL data sets.

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[2] Dalhousie University, Halifax, Nova Scotia B3H 3J5

Most of the strong SRCCs in the HP are readily related to magmatic minerals. Using conventional graphical techniques, MacDonald and Horne (1988) concluded that the principal factor controlling compositional variation in the HP was fractional crystallization with the removal of plagioclase, biotite, monazite, zircon, apatite, xenotime and rutile. Deuteric alteration features including albitization, K-feldspathization, chloritization and muscovitization increase with degree of fractionation, however, this alteration appears to have had little effect on most major and trace elements.

The strong SRCCs in the NL suite involve elements that tend to concentrate in late magmatic or hydrothermal stages of granitoid evolution. Distinguishing between these two influences is possible using SRCCs. For example, Na_2O and K_2O are erratically distributed in the HP data set and remain essentially constant from biotite granodiorite to coarse-grained leucomonzogranite in the HP (Fig. 2), but the significant negative correlation between these elements in the NL data suggests that albitization (NA) and K-feldspathization (K) may have been mutually exclusive processes in the most evolved rocks of the SMB. This indicates that NL rocks interacted with a residual fluid through fluid/melt or fluid/rock interaction. Also, the significant correlations involving P_2O_5 and Li in NL indicates an enrichment of these components into the residual fluid.

Finally, the SRCCs in the AL suite, intermediate between HP (magmatic) and NL (hydrothermal), suggests that these rocks retain evidence of both magmatic and hydrothermal influences, despite their substantial post-magmatic alteration (i.e. albitization, K-feldspathization, muscovitization) and low modal amounts of accessory minerals zircon, monazite and xenotime.

We have also evaluated the possible effects of closure (constant sum), variable compositional ranges, homogeneous vs. mixed data sets, and differing analytical precisions on the values of the SRCCs and conclude that none of these factors significantly changes the above conclusions. Spearman rank correlation coefficients can be used with compositional data drawn from populations with non-normal distributions to provide a rapid, non-graphical assessment of inter-element variations, to quantify these inter-element relationships, and to both identify processes, and gauge their contributions to the observed compositions. Key correlation coefficients might be used quantitatively to assess economic potential of granitoid suites.

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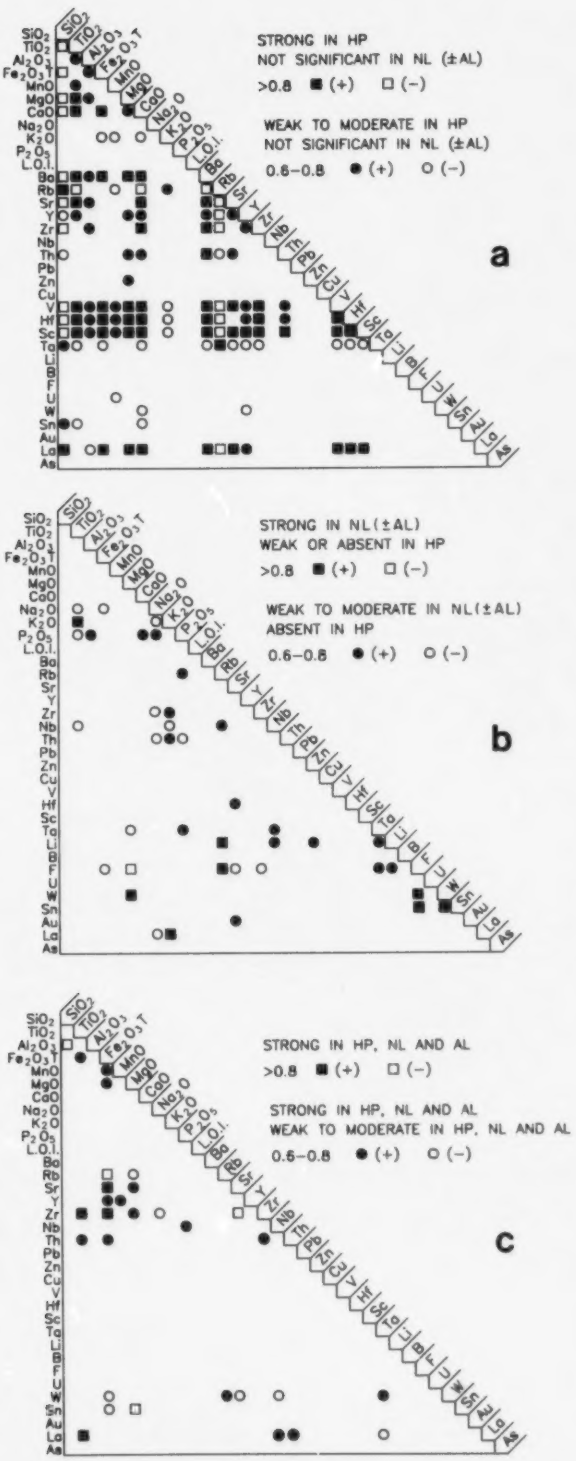

Figure 1. Moderate to strong Spearman rank correlation coefficients in: (a) the Halifax Pluton alone; (b) leucogranites of the South Mountain Batholith alone; (c) both the Halifax Pluton and the leucogranites.

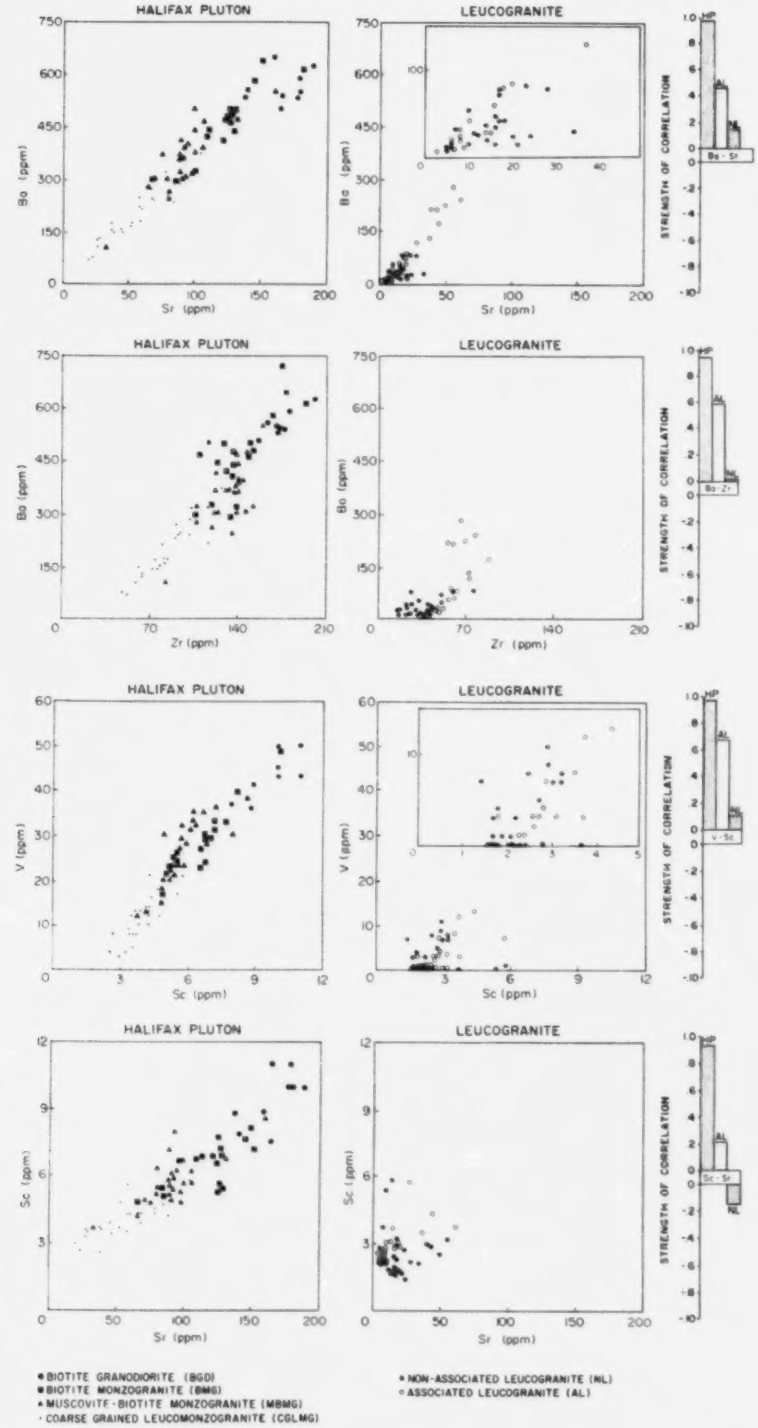

Figure 2. Bivariate plots and SRCCs for Ba-Sr, Ba-Zr, V-Sc and Sc-Sr from the HP, AL and NL data sets. The strong SRCCs in the HP result from fractional crystallization with the removal of plagioclase, biotite, monazite and zircon. Weak to moderate but significant correlations for these SRCCs in the AL data indicate the retention of a magmatic geochemical signature.

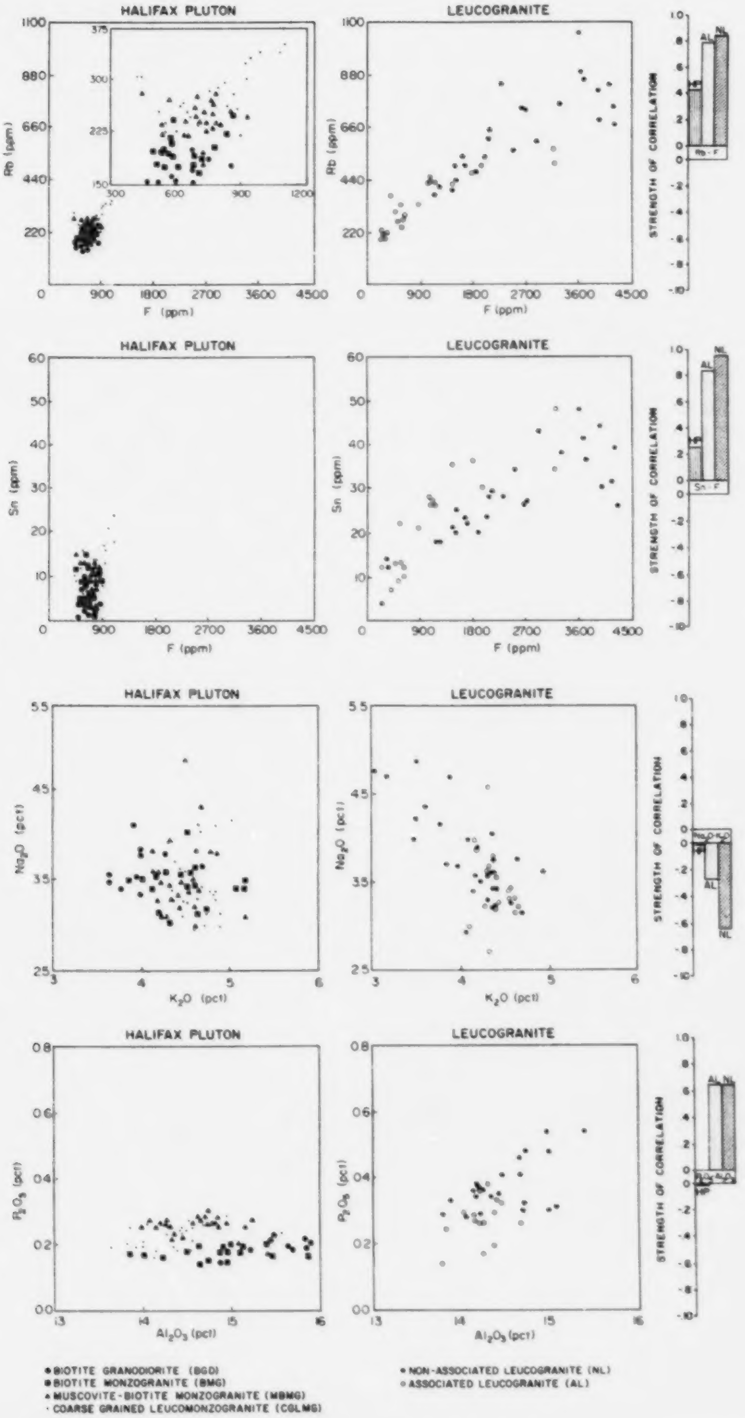

Figure 3. Bivariate plots and associated SRCCs for Rb-F, Sn-F, Na_2O-K_2O and P_2O_5-Al_2O_3 from the HP, AL and NL data sets. The strong SRCCs in the NL data signify hydrothermal alteration by a fluid enriched in Rb, F, Sn, Na ($\pm$K), P and Al.

NEW PALYNOLOGICAL AGE DATES, ZONATIONS, AND STRATIGRAPHY IN THE PERMO-CARBONIFEROUS STRATA OF THE CUMBERLAND BASIN, NOVA SCOTIA[1]

R. J. Ryan, R. C. Boehner, J. Calder and G. Dolby[2]

Approximately 400 palynological age dates were determined for strata from the Cumberland Basin of northern Nova Scotia. The continental dominated basin-fill is up to 7 km thick and ranges from Visean to early Permian in age (late Devonian to early Visean strata are present deep within the basin but are not sufficiently documented to be included).

The Cumberland (revised)/Riversdale Group rocks extend from Late Namurian to Late Westphalian C - early Westphalian D. Seven distinct informal spore assemblage zones have been recognized in these rocks, strata of zones 1 to 6 (Late Namurian to early Westphalian C) occur along the Joggins shoreline, from Downing Cove to Spicers Cove. Zone 7 assemblages (Westphalian C-D) are found in the Malagash Formation throughout most of the basin. The Pictou Group (revised) ranges in age from late Westphalian D to Stephanian in the Balfron and Tatamagouche Formations to early Permian in the Cape John Formation. Spore samples from the Mabou Group (Canso) Middleborough Formation, and adjacent rocks units, suggest a Viséan to Namurian age. The Middleborough is in part an age equivalent to the upper Windsor Group.

Substantial reworking of spores was found to occur throughout the basin and especially in the Joggins Section. Similar reworking of spores is recognized in the Sydney Basin. Abundant, well preserved, allochthonous material indicates extensive recycling and therefore extreme caution must be used in interpreting small data sets or individual samples. The recycling appears to be cyclic in nature and may reflect periods of uplift and erosion of Carboniferous strata on adjacent highland/platform areas. The palynological results are extremely valuable in establishing relationships within and between lithostratigraphic units in the basin. Although diachronous units are problematic the sampling density has closely defined the limits of these relationships. The division between the Westphalian A and B boundary based on international assemblage ranges is not clear, even though rocks can be well defined in relative age relationships using the local informal zonations. There does not appear to be any significant break in age between the Riversdale and the Cumberland Groups in the basin, and given their lithological similarities, the usefulness of the term Riversdale Group becomes obscure.

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[2] Dolby and Associates, 6719 Leaside Drive SW, Calgary, Alberta

COMPARISON OF APATITE FISSION TRACK LENGTH SPECTRA AND ORGANIC MATURATION INDICATORS IN THE MARITIMES BASIN, EASTERN CANADA[1]

R. J. Ryan, A. M. Grist[2], M. Zentilli[2] and R. C. Boehner

This study attempts to establish the relationship between apatite fission track length spectra and organic maturation indicators in the Late Devonian to Early Permian strata of the Maritimes Basin, in order to derive thermal profiles for the basin.

Fission track length measurements are compared to the Ro values of vitrinite samples from 1 km deep drillholes in the Cumberland and Sydney Basins (sub-basins). The drillholes studied show erratic vitrinite reflectance profiles which are typical of many drillholes in the basin. In the literature, these have been explained as resulting from variables such as time, temperature, pressure, and oxygen fugacity. The variability of the Ro values may be related to the presence of faults, recycled organic matter, changes in the type of organic matter, proximity to intrusions, thermal conductivity contrasts related to lithologic boundaries, coalification jumps, and gas-bearing sequences. The presence of marcasite and pyrite in the drillholes suggests that secondary effects of oxidation and chemical alteration, related to low temperature sulphide mineralization, may be significant variables contributing to the erratic Ro profiles. Unlike the organic indicators apatite fission tracks are only affected by temperature. For example, preliminary results from the Cumberland Basin drillhole SA-1+2 reveal that track lengths progressively shorten from a mean of 14.8 microns at 3056 m to 12.8 microns near the bottom of the hole at 1030 m. The fission track length spectra do no correlate with the inconsistent ("kinky") downhole distributions in the Ro values which vary from 1.09 to 2.05.

The results from this study indicate that apatite fission track length analyses, when combined with the organic maturation methods can isolate the temperature variable from other controlling factors which affect organic maturation.

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[2] Department of Geology, Dalhousie University, Halifax, N.S. B3H 3J5

RAPID LATE-GLACIAL CLIMATIC FLUCTUATIONS IN ATLANTIC CANADA[1]

R. J. Mott[2] and R. R. Stea

Throughout Atlantic Canada, numerous buried organic deposits and lake sediment sequences record a late-glacial climatic oscillation that has been equated with the Allerod/Younger Dryas event of Europe. Radiocarbon dating of narrow increments of organic sediments from these cores and sections has defined a chronological framework for this abrupt and relatively short-lived climatic fluctuation.

Pollen analysis shows that tundra-like vegetation of herbs and shrubs invaded the region as deglaciation proceeded. Reliable basal dates on organic sediments exceed 12 000 years B. P., with some exceeding 13 000 years B. P. in the earliest deglaciated areas. As the climate warmed, open woodlands of aspen/poplar and/or spruce migrated into the region in a general southwest to north and northeast direction. By 11 000 years B. P., deglaciation may have been complete or glaciers may have been reduced to small remnant masses in isolated areas. Trees had invaded southern and eastern New Brunswick and southern and north-central Nova Scotia, but not northern New Brunswick or northeastern Nova Scotia and Cape Breton Island. An abrupt climatic cooling reversed this process shortly after 11 000 and certainly by 10 800 years B. P. Arboreal taxa were depleted and shrubs and herbs were favoured. Mass wasting and solifluction on slopes no longer stabilized by vegetation covered organic deposits with mineral sediments and increased mineral sediment deposition in lakes. Remnant ice masses were rejuvenated and glaciers were regenerated in some areas. Climate began to warm again by about 10 400 to 10 200 years B. P., and by 9500 to 9600 years B. P. Holocene warming was well advanced and vegetation had proliferated in all areas.

These results indicate that within 200 years or possibly less, the climate cooled dramatically throughout Atlantic Canada and remained cool for several hundred years before a warming trend returned. Several possible causes for the Younger Dryas cooling have been proposed. Diversion of meltwaters from the Mississippi drainage way to the St. Lawrence River and the North Atlantic has recently been revived as a possible triggering mechanism for the cooling.

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[2] Geological Survey of Canada, Ottawa, Ontario

NEW QUATERNARY AGE DATES IN ATLANTIC CANADA[1]

R. R. Stea and R. J. Mott[2]

Dating events older than 50,000 years BP, the limit of the radiocarbon method, has been a major drawback in assessing the chronology of the Quaternary. Recently several new methods have been applied to the dating of buried forest and sea beds exposed in the Nova Scotia. These methods include U/Th disequilibrium dating of wood, amino acid racemization dating of shells and wood, and electron spin resonance dating of shells. These methods are not without problems, and must be assessed together and in concert with geological evidence in establishing a chronology. Using this approach a new chronology has emerged. Deposits of the penultimate interglacial (marine isotopic stage 7) have been found in southern Nova Scotia. The last interglacial has been subdivided into three units corresponding to marine isotope stages 5a, 5c and 5e. Mid-Wisconsinan (60,000 - 30,000 yrs BP) radiocarbon and U/Th dates on some of the forest beds have pushed up the limit of this non-glacial interval but the validity of these dates are suspect.

Many new dates have been obtained from the interval 14,000 -10,000 years BP. Evidence for change from warmer to cold climate around 11,000 has been established by dating pollen transition zones in lakes and buried organic beds. This fluctuation correlates with the Younger Dryas-Allerod oscillation of Europe. Rapid climatic change is indicated by synchronous glacial buildup and advances.

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[2] Geological Survey of Canada, Ottawa, Ontario

WISCONSINAN CHRONOLOGY IN EASTERN CANADA: LONG OR SHORT?[1]

R. R. Stea and R. J. Mott[2]

At least three major ice flow events are known to have affected the provinces adjacent to the Bay of Fundy during the Wisconsinan Stage. The first flow was generally southeastward across the Bay from an Appalachian or Laurentide source. It can be traced across Nova Scotia and offshore. The Escuminac Ice Center then developed in the lowlands northeast of the Bay of Fundy and flowed radially across northern Nova Scotia and southern New Brunswick. It transported material from Carboniferous redbed sources across Nova Scotia and offshore. The last major event was the development of local ice centers and divides in New Brunswick and Nova Scotia. Ice from the Scotian Ice Divide in Nova Scotia also terminated offshore. There is some evidence of ice retreat between these phases. It is not certain when these glaciers first developed. The first and most extensive ice flow event, the Fundy Stade, was placed in the Early Wisconsinan. Tills formed during this flow were deposited on interglacial forest and marine beds and a raised marine platform presumed to have formed during the last interglacial. A shorter chronology has now been proposed. Mid-Wisconsinan U/Th dates and finite radiocarbon dates have squeezed the ice flow events into the Late Wisconsinan. The same beds that have produced finite radiocarbon dates, however, have yielded infinite radiocarbon dates and U/Th dates as old as 98,000 yr B.P. The multi-till record in mainland Nova Scotia with the possibility of ice retreat phases, and the lack of finite Mid-Wisconsinan dates on wood, mitigate against a shortened chronology.

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[2] Geological Survey of Canada, Ottawa, Ontario

PRE-MESOZOIC TERRANES IN CIRCUM-ATLANTIC PHANEROZOIC OROGENS[1]

J. D. Keppie and R. D. Dallmeyer[2]

Pre-Mesozoic terranes within circum-Atlantic Phanerozoic orogens have been compiled by members of I.G.C.P. Project #233 on a Permian palinspastic reconstruction, i.e. a closed Atlantic Ocean. Application of the terrane concept originally proposed for the circum-Pacific orogens has required some modification of the definition in the circum-Atlantic orogens. Thus, a terrane is redefined as an area characterized by an internal continuity of geology (including stratigraphy, fauna, structure, metamorphism, igneous petrology, metallogeny, geophysical properties and paleomagnetic record) that is bounded by faults or melanges representing a trench complex, or a cryptic suture across which neighbouring terranes (1) may have a distinct geological record not explicable by facies changes (i.e. exotic terranes), or (2) may have a similar geological record (i.e. proximal terranes) that may only be distinguished by the presence of the terrane boundary representing telescoped oceanic lithosphere. The terranes are categorized by age and tectonic setting: autochthonous and imbricated basement/miogeocline, continental rise, oceanic lithosphere, oceanic sequence, magmatic arc complex, periarc basin, trench complex, disrupted terrane (tectonic melange), metamorphic rocks of uncertain protolith, continental rocks of uncertain affinity, and continental rift rocks of uncertain affinity. Most oceanic terranes appear to represent small ocean basins rather than fragments of the main oceans. Also shown are post-accretionary stitching plutons, overstep sequences and accretionary diagrams for various sections of the orogens.

The major cratonic terranes and their miogeoclines around the margins of the circum-Atlantic Paleozoic orogens are structurally separated from the magmatic arc and oceanic terranes, which occur in the internal and uppermost structural parts of the various orogens. Disrupted terranes, mainly consisting of blocks of ophiolite, oceanic and periarc rocks set in a foliated matrix of miogeoclinal and continental rise affinities, generally occur along the margins of the major cratonic terranes. Precambrian rocks in the major cratonic terranes bordering the circum-Atlantic Phanerozoic orogens show a wide range of age: Archean, Early Proterozoic and Middle Proterozoic (Grenvillian) occur in Baltica, Laurentia and South America -- Grenvillian is absent in north-western Africa. Continental terranes with Archean-Proterozoic basement are scattered throughout the circum-Atlantic Phanerozoic orogens, however the widespread distribution of such rocks in the surrounding major cratonic terranes indicates that the age of the basement alone is not a unique feature for distinguishing kinship. The Late Precambrian terranes are limited to the southeastern part of the map: central/western Europe, southern British Isles, southeastern Appalachians, northwest Africa and northern South America and were accreted in Late

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[1] In 28th International Geological Congress, Washington, D.C., July 9-19, 1989; Abstracts, volume 2 of 3, p. 2-176.

[2] Department of Geology, University of Georgia, Athens, Georgia, U.S.A. 30603

Precambrian - Cambrian orogens. These latter orogens were developed across Precambrian rocks ranging from Archean to Middle Proterozoic and their accretional activity overlapped the time span for the opening of Iapetus, suggesting that they originated in a separate ocean. Magmatic arc and periarc terranes are well preserved in some of the Late Precambrian - Cambrian orogens in contrast to their poor representation in the Paleozoic orogens. As magmatic arcs lie on the upper plate, they would probably be removed by erosion following continental collision. Thus, their preservation in the Late Precambrian - Cambrian orogens suggests that such collisions did not occur. Overstep sequences across the Late Precambrian terranes may become miogeocline relative to the Phanerozoic orogens.

Most of the identified Paleozoic, ophiolitic, magmatic arc and oceanic terranes in the circum-Atlantic Phanerozoic orogens appear to have formed during the Cambro-Ordovician, with relatively few such terranes of Silurian-Carboniferous age occurring mainly in western and central Europe. This suggests that Iapetus was essentially closed by the end of the Early Paleozoic. This is consistent with the presence of distinct faunal provinces during the Cambro-Ordovician followed by a cosmopolitan fauna in the Siluro-Devonian. Late Paleozoic orogenic activity is inferred to be mainly transpressive along the vestiges of Iapetus, while convergence was still taking place in the Variscan orogen. The scale of Late Paleozoic transcurrent and rotational movements is presently uncertain and several widely divergent models based upon paleomagnetic data are current. These Late Paleozoic movements must be unravelled before an objective palinspastic model for the Early Paleozoic development of the circum-Atlantic Phanerozoic orogens can be developed. Many current models involve orthogonal opening and closing, and ignore the possibility of large transcurrent movements. The map of Precambrian-Paleozoic terranes in circum-Atlantic Phanerozoic orogens provides one source of data for such a genetic model. The terrane map provides the base for other thematic maps, showing metamorphic and structural data, for example.

NORTHERN APPALACHIAN TERRANES: THEIR NATURE AND ACCRETIONARY HISTORY[1]

J. D. Keppie

Recent geological mapping in the northern Appalachians has provided an improved database for delineating terranes and providing better constraints on their accretionary history. A revised terrane map of the northern Appalachians is presented along with a series of diagrams outlining their accretionary history. The terranes may be grouped into the following categories from northwest to southeast:

(1) North American terrane characterized on its eastern side by Grenvillian basement overlain successively by a Late Precambrian-Ordovician miogeocline (containing Cu-Zn-Ag in tholeiitic rift volcanic rocks and Mississippi Valley type Zn deposits) and an Ordovician foredeep;

(2) disrupted terranes composed of a tectonic melange of blocks of ophiolite, oceanic and periarc rocks set in a matrix of continental rift-rise (containing remobilized sedimentary Cu) and lying along the disrupted continent-ocean transition zone;

(3) terranes composed of Late Precambrian continental rise and Late Cambrian-Early Ordovician oceanic lithosphere (typically containing chromite and asbestos in the ultramafic rocks, Cu±Zn(±Ag±Pb±Au) veins and massive sulphide deposits in the overlying tholeiitic volcanic rocks, and metamorphic-hydrothermal Sb±Mo±Au±Cu±Pb±Zn quartz veins produced during the regional metamorphism) thrust over the North American terrane;

(4) diverse Cambro-Ordovician terranes made up of magmatic arcs and rifted magmatic arcs, periarc basins (hosting Cu-Zn-Pb±Au±Ag±Sb massive sulphide deposits), discontinuous continental rise deposits and microcontinents with Precambrian basement, which represent the vestiges of Iapetus;

(5) diverse Precambrian rocks characterized by metamorphosed middle Proterozoic rocks (containing Pb-Zn-Cu-W skarns), Late Precambrian volcanic rocks of continental rift and cratonic magmatic arc-intraarc rifts (containing Zn-Cu-Pb±Au±Ag massive sulphides and Cu-Mo porphyries), many overlain by outliers of similar Cambro-Ordovician strata containing an Atlantic fauna and interpreted as the remnants of an overstep sequence across the older units and define the Avalon Composite terrane;

(6) Meguma terrane composed of Cambro-Ordovician turbidites.

These terranes are overstepped by Siluro-Devonian shallow marine - continental strata with tholeiitic rift volcanic rocks (containing

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[1] In 28th International Geological Congress, Washington, D.C., July 9-19, 1989; Abstracts, volume 2 of 3, p. 2-177.

Cu±Pb±Zn±Ag) and generally continental Devono-Carboniferous sequences (containing limestone-hosted Cu-Zn-Ba, sandstone-hosted Pb-Cu-U and placer Au mineralization, evaporites and coal). Faunal provinciality evident in the Cambro-Ordovician becomes cosmopolitan in the Siluro-Devonian. Devonian (Carboniferous) stitching plutons are widespread across the northern Appalachians (except in the Avalon Zone in Newfoundland) and are related to a gradual rise of the isotherms following tectonic loading of the lithosphere by obduction. These plutons are associated with polymetallic mineralization varying from Sn-U in the southeast to Cu-Mo in the northwest, which may be related to the change in the nature of the crust at depth.

The structural geometry of the northern Appalachians shows a fold and thrust vergence outwards from the axis of the Central Mobile belt. The nature of the fault along the northwestern boundary of the Avalon composite terrane varies with age from a vertical Late Silurian-Early Devonian fault in Newfoundland, through a westerly vergent Early-Middle Devonian thrust in New Brunswick to an easterly vergent Late Devonian-Carboniferous-Early Permian thrust in New England. The Meguma terrane appears to be thrust northwestwards over the Avalon composite terrane. The accretionary history of these terranes may be broadly subdivided into the following sequence:

(1) Late Precambrian amalgamation of the Avalon Composite terrane during the Cadomian Orogeny is constrained by the similarity of the Cambro-Ordovician outliers which are inferred to represent a formerly continuous overstep sequence;

(2) progressive oblique dextral convergence in the northwestern part of Iapetus between North America and a volcanic arc (Ascot-Weedon-Notre Dame) throughout the Ordovician culminated in continent-arc collision and accretion of intervening terranes;

(3) progressive oblique sinistral convergence in the southeastern part of Iapetus beneath a volcanic arc complex (Bronson Hill-Mirimichi-La Poile) throughout the Ordovician, Silurian and Early Devonian led to closure of Iapetus and amalgamation of intervening terranes and sinistral emplacement of the Avalon Composite terrane along a deep vertical fault (Dover-Turtle Head Fault);

(4) progressive oblique dextral closure of the Theic Ocean between Avalonia and Gondwana led to accretion of the Meguma terrane by earliest Devonian and culminated in progressive continent-continent collision throughout the Devonian, Carboniferous and early Permian.

1:5,000,000 MAP OF PRE-MESOZOIC TERRANES IN CIRCUM-ATLANTIC PHANEROZOIC OROGENS[1]

J. D. Keppie and R. D. Dallmeyer[2]

This map depicts Precambrian-Paleozoic terranes within circum-Atlantic Phanerozoic orogens on a Permian palinspastic reconstruction (transverse Mercator projection). The terranes are categorized by age and tectonic setting: autochthonous and imbricated basement/miogeocline, continental rise, oceanic lithosphere, oceanic sequence, magmatic arc complex, periarc basin, trench complex, disrupted terrane (tectonic melange), metamorphic rocks of uncertain protolith, continental rocks of uncertain affinity, and continental rift rocks of uncertain affinity. Also shown are post-accretionary stitching plutons, overstep sequences and accretionary diagrams for various sections of the orogens. Continental terrances with Archean-Proterozoic basement are scattered throughout the circum-Atlantic Phanerozoic orogens. The Late Precambrian terranes are limited to the southeastern part of the map. Magmatic arc and periarc terranes are well preserved in some of the Late Precambrian-Cambrian orogens in contrast to their poor representation in the Paleozoic orogens. Most oceanic terranes appear to represent small ocean basins rather than fragments of the main oceans. Most of the identified Paleozoic, ophiolitic, magmatic arc and oceanic terranes in the circum-Atlantic Phanerozoic orogens appear to have formed during the Cambro-Ordovician, with relatively few such terranes of Silurian-Carboniferous age occurring mainly in western and central Europe.

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[1] In 24th Annual Meeting, Northeastern Section, The Geological Society of America, New Brunswick, New Jersey, March 23-25, 1989; Abstracts with Programs 1989, v. 21, no. 2, p. 26.

[2] Department of Geology, University of Georgian, Athens, Georgia, U.S.A. 30602

1:5,000,000 MAP OF PRECAMBRIAN AND PALEOZOIC TERRANES IN CIRCUM-ATLANTIC PHANEROZOIC OROGENS[1]

J. D. Keppie and R. D. Dallmeyer[2]

This map depicts Precambrian-Paleozoic terranes within circum-Atlantic Phanerozoic orogens on a Permian palinspastic reconstruction, i.e. a closed Atlantic Ocean. The base map is a transverse Mercator projection with the Equator along the axis of the closed Atlantic. The terranes are categorized by age and tectonic setting: autochthonous and imbricated basement/miogeocline, continental rise, oceanic lithosphere, oceanic sequence, magmatic arc complex, periarc basin, trench complex, disrupted terrane (tectonic melange), metamorphic rocks of uncertain protolith, continental rocks of uncertain affinity, and continental rift rocks of uncertain affinity. Most oceanic terranes appear to represent small ocean basins rather than fragments of the main oceans. Also shown are post-accretionary stitching plutons, overstep sequences and accretionary diagrams for various sections of the orogens.

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[1] In 28th International Geology Congress, Washington, D.C., July 9-19, 1989: Abstracts, volume 2 of 3, p. 2-177.

[2] Department of Geology, University of Georgia, Athens, Georgia, U.S.A. 30603

Most of the identified Paleozoic, ophiolitic, magmatic arc and oceanic terranes in the circum-Atlantic Phanerozoic orogens appear to have formed during the Cambro-Ordovician, with relatively few such terranes of Silurian-Carboniferous age occurring mainly in western and central Europe. This suggests that Iapetus was essentially closed by the end of the Early Paleozoic. This is supported by the presence of distinct faunal provinces in the Cambro-Ordovician followed by a cosmopolitan fauna in the Siluro-Devonian. Late Paleozoic orogenic activity is inferred to be mainly transpressive along the vestiges of Iapetus, while convergence was still taking place in the Variscan orogen. The scale of Late Paleozoic transcurrent and rotational movements is presently uncertain and several widely divergent models based upon paleomagnetic data are current. These Late Paleozoic movements must be unravelled before an objective palinspastic model for the Early Paleozoic development of the circum-Atlantic Phanerozoic orogens can be developed. Many current models involve orthogonal opening and closing, and ignore the possibility of large transcurrent movements. The map of Precambrian-Paleozoic terranes in circum-Atlantic Phanerozoic orogens provides one source of data for such a genetic model. The terrane map provides the base for other thematic maps, showing metamorphic and structural data, for example.

ACCRETIONARY HISTORY OF PRE-MESOZOIC TERRANES IN CIRCUM-ATLANTIC PHANEROZOIC OROGENS[1]

J. D. Keppie and R. D. Dallmeyer[2]

The accretionary history of pre-Mesozoic terranes in Circum-Atlantic Phanerozoic orogens may be broadly divided into:

(1) terranes located in northwestern Africa, central/western Europe, southern British Isles, southeastern Appalachians and northern South America, which were accreted during the latest Proterozoic-Cambrian during the Pan African-Cadomian Orogeny;

(2) terranes located in the Appalachians, the Caledonides of Greenland, Svalbard, Scandinavia and the British Isles, and the Variscides of central/western Europe and northwest Africa, which were mainly accreted during the Early Paleozoic with a few accretionary events occurring in the Devono-Carboniferous (mainly in the Variscides);

(3) terranes located in the Alpine and Andean orogens many of which still retain evidence of their Late Paleozoic overstep sequence.

Some terranes have suffered a poly-orogenic history involving alternating accretion and dispersion.The synchroneity of convergence in the Pan-African terranes and the opening of Iapetus suggest that these events were taking place in widely separate regions. Palinspastic models for Precambrian-Early Paleozoic are presently poorly constrained by paleomagnetic data. However, the following tentative model may be proposed when paleomagnetic data are combined with paleontological and tectonic data from the map of pre-Mesozoic terranes in circum-Atlantic Phanerozoic orogens:

(1) latest Proterozoic-Cambrian separation South America and Baltica from Laurentia is constrained by contemporaneous passive margin sequences and took place concurrently with convergence along an ocean-continent (±island arcs) boundary in Pan-African orogens along the northern margin of Africa and South America;

(2) Ordovician-Silurian sinistral convergence of Baltica and Gondwana (?South America) with Laurentia, ending with the virtual elimination of Iapetus, is constrained by the presence of similar, Late Siliurian freshwater vertebrates on both Baltica and Laurentia and Early Devonian, Eastern Americas brachiopod Faunal Realm in Laurentia and northern South America;

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[1] In 28th International Geological Congress, Washington, D.C., July 9-19, 1989; Abstracts, volume 2 of 3, p. 2-178.

[2] Department of Georgia, University of Georgia, Athens, Georgia, U.S.A. 30603

(3) Devono-Carboniferous dextral convergence across the Variscides and the Appalachians may be related to anticlockwise rotation of Gondwana relative to Laurentia.

Within this general scenario, the geological record of individual terranes provides some constraints upon their origin.

AVALON COMPOSITE TERRANE OF NORTHERN APPALACHIANS: POSSIBLE CORRELATIVES[1]

J. B. Murphy[2], J. D. Keppie, R. D. Nance[3] and J. Dostal[4]

The Avalon Composite terrane is defined by its distinctive, platformal, Cambro-Ordovician, overstep sequence, which contains an Acado-Baltic fauna, in turn overlain by the Siluro-Devonian shelf sequence containing a Rhenish-Bohemian fauna. On this basis, the Avalon Composite terrane extends from eastern Newfoundland through northern Nova Scotia, southern New Brunswick and Maine to southern New England (Figure 1). The early Paleozoic rocks overstep a variety of distinct Precambrian terranes: (1) A continental rift sequence in easternmost Newfoundland ranging in age from 583 to 633 Ma. (2) An ocean-floor sequence dated at 762 ± 2 Ma in the Burin Peninsula of Newfoundland. (3) A cratonic magmatic arc sequence ranging in age from ca. 560 to 629 Ma in the western Avalon Composite terrane in Newfoundland. (4) A rifted cratonic magmatic arc complex consisting of alternating calcalkaline igneous rocks and cratonic intra-arc basin with rift volcanic rocks throughout Cape Breton Island, northern Nova Scotia, and southern New Brunswick. (5) A rifted cratonic magmatic arc complex with an internal intra-arc rift basin in southern New England.

The rocks beneath these Late Proterozoic rocks are only exposed in Maritime Canada. They consist of miogeoclinal rocks that in southern New Brunswick contain stromatolites of middle Riphean age. This unit in turn unconformably overlies a gneissic basement with radiometric ages of questionable value: (1) 814 Ma U-Pb age from a concordant zircon in the gneisses of southern New Brunswick is interpreted as the age of the metamorphism; (2) 934 ± 82 Ma Rb-Sr whole rock age from gneisses in the Cobequid Highlands interpreted as the metamorphic age; (3) 701 ± 66 Ma Rb-Sr whole rock age from the gneisses of Cape Breton Island interpreted as the metamorphic age; and (4) 1040 Ma U-Pb age from a metamorphosed syenite in northwestern Cape Breton Island is interpreted as the time of metamorphism.

The tectonic setting of the latter age is uncertain. It has been interpreted as the easternmost exposure of autochthonous North American, Grenvillian basement: however, reflection seismic data indicate that the top of the Grenvillian basement here is at a depth of >10 seconds (two-way travel time). Alternative interpretations include: (1) a proximal terrane rifted off North America and subsequently reaccreted during the Paleozoic orogenesis; (2) an exotic terrane rifted off some other Grenvillian orogen, e.g., southern Scandinavia or South America. The Middle Proterozoic age of the metamorphism in this block is consistent with the tentative age of metamorphism in the Avalonian terranes elsewhere in the Maritime Appalachians, and might suggest that the Late Proterozoic magmatic arc complex developed on a Grenvillian basement. The only region where a similar succession is present occurs in South America.

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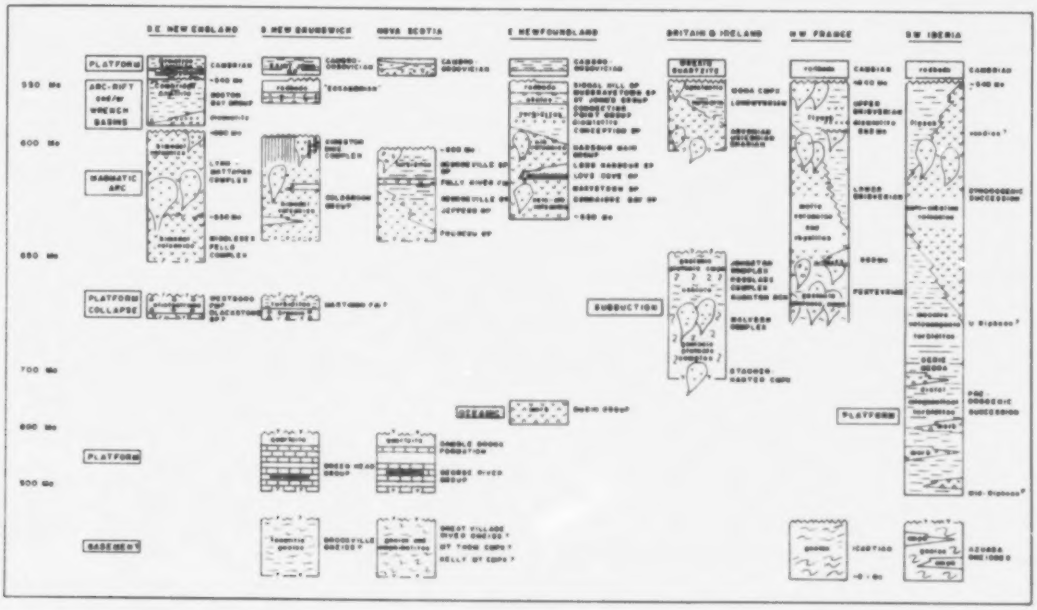
[1] In 28th International Geological Congress, Washington, D.C., July 9-19, 1989; Abstracts, volume 2 or 3, p. 2-483.

[2] St. Francis Xavier University, Antigonish, Nova Scotia

[3] Ohio University, Athens, OH

[4] St. Mary's University, Halifax, Nova Scotia


SE NEW ENGLAND
S NEW BRUNSWICK
NOVA SCOTIA
E NEWFOUNDLAND
BRITAIN & IRELAND
NW FRANCE
SW IBERIA
550 Ma
600 Ma
650 Ma
700 Ma
800 Ma
900 Ma
PLATFORM
ARC-RIFT and/or WRENCH BASINS
MAGMATIC ARC
PLATFORM COLLAPSE
PLATFORM
BASEMENT
SUBDUCTION
OCEANIC
PLATFORM
CAMBRIAN
CAMBRO-ORDOVICIAN
LYNN-MATTAPAN COMPLEX
MIDDLESEX FELLS COMPLEX
SIGNAL HILL GP
CONCEPTION GP
HARBOUR MAIN GROUP
LOVE COVE GP
SUBDUCTION
GREEN HEAD GROUP
GEORGE RIVER GROUP
GREAT VILLAGE RIVER GNEISS ?
KELLY MT COMPLEX ?
ICARTIAN
AZUAGA GNEISSES
U Riphean ?
Mid-Riphean ?

REASSESSMENT OF TERRANES IN THE AVALON COMPOSITE TERRANE OF ATLANTIC CANADA[1]

J. B. Murphy[2], J. D. Keppie, R. D. Nance[3] and J. Dostal[4]

The Avalon Composite terrane (ACT) in Atlantic Canada is defined by the presence of a lithostratigraphically correlative, subaerial-shallow marine, Cambro-Ordovician overstep sequence containing an Acado-Baltic fauna. These rocks rest upon a variety of Late Proterozoic volcanic rocks and turbidites (Coldbrook = Jeffers = Georgeville = Fourchu = Harbour Main) overlying Late/Middle Proterozoic or older metasediments (Green Head = Gamble Brook = George River = McMillan Flowage = Cape North) in tectonic contact with ?Mid/Late Proterozoic gneisses (Brookville = Great Village = Pleasant Bay = Polletts Cove Brook). Contrasts in this Precambrian stratigraphy led to subdivision into several Late Proterozoic terranes. However, new data in Nova Scotia and New Brunswick indicate that it comprises alternating horsts and grabens throughout and suggests that the ACT consists of a rifted magmatic arc complex lacking oceanic components. The ACT in Newfoundland may be divided into two Late Proterozoic, cratonic, rifted magmatic arc terranes separated by the ophiolitic Burin terrane, all overstepped by the latest Proterozoic Musgravetown Group. The four terranes proposed by Barr and Raeside (1986) in Cape Breton Island are here interpreted as different levels of erosion of the Avalonian magmatic arc complex.

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[1] In 24th Annual Meeting, Northeastern Section, The Geological Society of America, New Brunswick, New Jersey, March 23-25, 1989; Abstracts with Programs 1989, v. 21, no. 2, p. 54.

[2] Department of Geology, St. Francis Xavier University, Antigonish, N.S. B2G 1C0

[3] Department of Geological Scriences, Ohio University, Athens, Ohio 45701

[4] Department of Geology, St. Mary's University, Halifax, N.S. B3J 3C3

EPISODIC PROTEROZOIC-CAMBRIAN PLUTONISM IN THE AVALON COMPOSITE TERRANE IN NOVA SCOTIA: CONSTRAINTS FROM ^{40}AR/^{39}AR HORNBLENDE AGES[1]

J. D. Keppie, R. D. Dallmeyer[2] and J. B. Murphy[3]

The Avalon composite terrane (ACT) in Nova Scotia is interpreted as a Late Proterozoic, rifted, cratonic, magmatic arc complex lacking oceanic components. Overstepping, subaerial to shallow marine Cambro-Ordovician sequences are cut by the Macintosh Brook fault in the Boisdale Hills of Cape Breton Island, across which the proportion of volcanic rocks changes from minor (south) to major (north). ^{40}Ar/^{39}Ar hornblende plateau ages from plutons spatially associated with these volcanic rocks fall into three age brackets: (1) South of the MacIntosh Brook fault: (a) c. 608-630 Ma in the Stirling intra-arc rift; and (b) c. 615-630 Ma in the Huntington and Coxheath magmatic arc horsts; (2) North of the MacIntosh Brook fault: c. 525-550 Ma in the Boisdale, North Mountain and Craignish Hills; (3) In the Antigonish and Cobequid Highlands intra-arc rift: c. 600-630 Ma. These plutons were emplaced at relatively shallow crustal levels, therefore it is likely that the ^{40}Ar/^{39}Ar plateau ages closely date their emplacement. Published U-Pb ages confirm this conclusion and indicate the presence of c. 600 Ma plutons also in zone 2. Interpretation of the age data suggests that plutonism associated with the rifted magmatic arc lasted from c. 630-600 Ma. Igneous activity possibly associated with Cambrian bimodal rift volcanism was renewed between c. 550-525 Ma.

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[1] In 24th Annual Meeting, Northeastern Section, The Geological Society of America, New Brunswick, New Jersey, March 23-25, 1989; Abstracts with Programs 1989, v. 21, no. 2, p. 26.

[2] Department of Geology, University of Georgia, Athens, Georgia, U.S.A. 30602

[3] Department of Geology, St. Francis Xavier University, Antigonish, N.S. B2G 1C0

NEOTECTONIC AND PALEOSEISMIC PHENOMENA ALONG THE NORTH SHORE OF THE MINAS BASIN, NOVA SCOTIA[1]

T. R. Stokes[2] and J. D. Keppie

Structures affecting Late Wisconsinan sediments were found at 34 locations along the north shore of the Minas Basin: 29 in glacial outwash deltas of Saints Rest (SR) glacio-fluvial sediments and Advocate Harbour (AH) glacio-marine sediments, and 5 in Eatonville till. The most important structures are: (1) at Finney Brook where conjugate normal faults, which downthrow a 15-20m wide block of AH forset sands by c. 1-2m, are the probable result of a reactivated NE-SW bedrock fault; (2) at Lower Five Islands metre scale folds and associated faults, restricted to a horizon of AH bottomset muds, appear related to extension during delta slumping or bedrock movement; and (3) at Economy Point, major chaotic folds in AH bottomset muds, which occur beneath a thin (1-3m) undisturbed SR gravel layer, may be attributed to delta slumping or seismically induced liquidization. It is not possible to uniquely determine the origin of these structures: whether they be neotectonic, related to glacial processes or to glacial rebound. However, most are probably associated with paleoseismicity. Reflection seismic profiles (which indicate that NE-SW listric normal faults and E-W flower structures affect Mesozoic strata and the Cenozoic sea-bottom sediments), the present day NW-SW compressional stress regime and recent earthquake activity support the interpretation that the structures observed are possibly the result of neotectonic and paleoseismic activity associated with the genesis of Bay of Fundy.

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[1] In Geological Association of Canada - Mineralogical Association of Canada Annual Meeting, Montreal, Quebec, May 15-17, 1989; Program with Abstracts, v. 14, p. A105-A106.

[2] Prospect Bay Consulting Services, 143 Brennans Road, P. O. Box 25, RR#4, Armdale, Nova Scotia B3L 4J4

IMPLICATIONS OF ^{40}AR/^{39}AR HORNBLENDE AGES FROM LATE PROTEROZOIC-CAMBRIAN PLUTONS IN THE AVALON COMPOSITE TERRANE OF NOVA SCOTIA[1]

J. D. Keppie, R. D. Dallmeyer[2] *and J. B. Murphy*[3]

The Avalon Composite Terrane in Nova Scotia mainly represents a late Proterozoic, rifted, cratonic, magmatic arc complex. The geochemistry of the volcanic rocks indicates that most of southeastern Cape Breton Island is underlain by a volcanic arc, whereas the Antigonish and Cobequid Highlands expose intra-arc rift sequences. These units are unconformably overlain by subaerial to shallow marine Cambrian-Ordovician sedimentary sequences containing an Atlantic fauna that are interbedded with Early to Middle Cambrian, within-plate, continental rift volcanic rocks. ^{40}Ar/^{39}Ar plateau ages recorded by hornblende from plutons spatially associated with these volcanic rocks correspond to three groupings: (1) c. 600-635 Ma in Cape Breton Island south of the MacIntosh Brook fault (traversing the Boisdale Hills); (2) c. 525-555 Ma in Cape Breton Island north of the MacIntosh Brook fault (Boisdale Hills, North Mountain and Creignish Hills); (3) c. 600-635 Ma in the Antigonish and Cobequid Highlands. Based upon the low metamorphic grade of the late Proterozoic and early Paleozoic rocks, and the low pressures recorded in contact aureoles and plutons, it is inferred that these plutons were emplaced at relatively shallow crustal levels, and therefore the ^{40}Ar/^{39}Ar plateau ages probably closely date their emplacement. Interpretation of the age data suggest that plutonism in Nova Scotia associated with the rifted magmatic arc lasted from c. 635-600 Ma. Igneous activity continued between c. 555-525 Ma and may have been related to the Cambrian, within-plate, rift volcanism.

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[2] Department of Geology, University of Georgia, Athens, Georgia 30602

[3] Department of Geology, St. Francis Xavier University, Antigonish, Nova Scotia B2G 1C0

TECTONIC MAP OF PRE-MESOZOIC TERRANES IN CIRCUM-ATLANTIC PHANEROZOIC OROGENS[1]

J. D. Keppie and R. D. Dallmeyer[2]

This map depicts Precambrian-Paleozoic terranes within circum-Atlantic Phanerozoic orogens on a Permian palinspastic reconstruction, i.e. a closed Atlantic Ocean. The base map is a traverse Mercator projection with the Equator along the axis of the closed Atlantic. The terranes are categorized by age and tectonic setting: autochthonous and imbricated basement/miogeocline, continental rise, oceanic lithosphere, oceanic sequence, magmatic arc complex, periarc basin, trench complex, disrupted terrane (tectonic melange), metamorphic rocks of uncertain protolith, continental rocks of uncertain affinity, and continental rift rocks of uncertain affinity. Most oceanic terranes appear to represent small ocean basins rather than fragments of the main oceans. Also shown are post-accretionary stitching plutons, overstep sequences and accretionary diagrams for various sections of the orogens.

The major cratonic terranes and their miogeoclines around the margins of the circum-Atlantic Paleozoic orogens are structurally separated from the magmatic arc and oceanic terranes, which occur in the internal and uppermost structural parts of the various orogens. Disrupted terranes, mainly consisting of blocks of ophiolite, oceanic and periarc rocks set in a foliated matrix of miogeoclinal and continental rise affinities, generally occur along the margins of the major cratonic terranes. Precambrian rocks in the major cratonic terranes bordering the circum-Atlantic Phanerozoic orogens show a wide range of age: Archean, Early Proterozoic and Middle Proterozoic (Grenvillian) occur in Baltica, Laurentia and South America -- Grenvillian is absent in north-western Africa. Continental terranes with Archean-Proterozoic basement are scattered throughout the circum-Atlantic Phanerozoic orogens, however the widespread distribution of such rocks in the surrounding major cratonic terranes indicates that the age of the basement alone is not a unique feature for distinguishing kinship. The Late Precambrian terranes are limited to the southeastern part of the map: central/western Europe, southern British Isles, southeastern Appalachians, northwest Africa and northern South America and were accreted in Late Precambrian - Cambrian orogens. These latter orogens were developed across Precambrian rocks ranging from Archean to Middle Proterozoic and their accretional activity overlapped the time span for the opening of Iapetus, suggesting that they originated in a separate ocean. Magmatic arc and periarc terranes are well preserved in some of the Late Precambrian - Cambrian orogens in contrast to their poor representation in the Paleozoic orogens. As magmatic arcs lie on the upper plate, they would probably be removed by erosion following continental collision. Thus, their preservation in the Late Precambrian - Cambrian orogens suggests that such collisions did not occur. Overstep sequences across the Late Precambrian terranes may become miogeocline relative to the Phanerozoic orogens.

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[1] In IGCP Symposium, Tectonostratigraphic Expression of Terrane Acretion in the Circum-Atlantic Paleozoic Orogens, Athens, Georgia, July 21-22, 1989; Abstracts and Program, p. 49-50.

[2] Department of Geology, University of Georgia, Athens, Georgia, U.S.A. 30602

Most of the identified Paleozoic, ophiolitic, magmatic arc and oceanic terranes in the circum-Atlantic Phanerozoic orogens appear to have formed during the Cambro-Ordovician, with relatively few such terranes of Silurian-Carboniferous age occurring mainly in western and central Europe. This suggests that Iapetus was essentially closed by the end of the Early Paleozoic. This is supported by the presence of distinct faunal provinces in the Cambro-Ordovician followed by a cosmopolitan fauna in the Siluro-Devonian. Late Paleozoic orogenic activity is inferred to be mainly transpressive along the vestiges of Iapetus, while convergence was still taking place in the Variscan orogen. The scale of Late Paleozoic transcurrent and rotational movements is presently uncertain and several widely divergent models based upon paleomagmetic data are current. These Late Paleozoic movements must be unravelled before an objective palinspastic model for the Early Paleozoic development of the circum-Atlantic Phanerozoic orogens can be developed. Many current models involve orthogonal opening and closing, and ignore the possibility of large transcurrent movements. The map of Precambrian-Paleozoic terranes in circum-Atlantic Phanerozoic orogens provides one source of data for such a genetic model. The terrane map provides the base for other thematic maps, showing metamorphic and structural data, for example.

TECTONIC MAP OF PRE-MESOZOIC TERRANES IN CIRCUM-ATLANTIC PHANEROZOIC OROGENS: A 1:5,000,000 COMPILATION[1]

J. D. Keppie and R. D. Dallmeyer[2]

This map depicts the terranes on a Traverse Mercator Projection palinspastically reconstructed for Permian Times, i.e. a closed Atlantic Ocean. The map shows the terranes categorized by their age (ranging from c. 700-250 Ma) and tectonic setting: autochthonous and imbricated basement/miogeocline, continental rise, oceanic lithosphere, oceanic sedimentary/volcanic sequence, magmatic arc complex, intra-arc basin, periarc basin, trench complex, and units of uncertain affinity (metamorphic rocks, continental rift rocks and continental crust). Correlations across Mesozoic/Tertiary orogens require the depiction of Precambrian and Paleozoic terranes in these orogens. Also shown are post-accretionary stitching plutons, overstep sequences and accretionary diagrams for various sections of the orogens.

The major cratonic terranes and their miogeoclines are structurally separated from the magmatic arc and oceanic terranes, which occur in the internal and uppermost structural parts of the orogens. The Late Precambrian terranes are limited to the southeastern part of the map and their accretionary activity overlapped the time span for the opening of Iapetus. Most of the identified Paleozoic, magmatic arc and oceanic terranes appear to have formed during the Cambro-Ordovician, with relatively few terranes formed during Silurian-Carboniferous times. Most oceanic terranes appear to represent small ocean basins rather than fragments of the main oceans.

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[1] Papper presented at the Atlantic Geoscience Society Colloquium on Current Research in the Atlantic Provinces, Wolfville, Nova Scotia, February 9-10, 1990

[2] Department of Geology, University of Georgia, Athens, Georgia 30602

RECONNAISSANCE AND DETAILED GEOCHEMICAL SURVEYS FOR GOLD IN EASTERN NOVA SCOTIA USING PLANTS, LAKE SEDIMENT, SOIL AND TILL[1]

C. E. Dunn[2], W. B. Coker[2] and P. J. Rogers

Reconnaissance-level geochemical surveys of similar sample density and areal extent were conducted using lake sediment and twigs of balsam fir (*Abies balsamea*). Both sample media successfully delineate Au districts in eastern Nova Scotia. A moderately good spatial relationship between the data sets for Au and As suggests that either medium may be used to identify gold-bearing zones.

Detailed sampling near Au mineralization permitted comparison of distribution patterns of Au, As, and Sb in outer bark of red spruce (*Picea rubens*), and several size fractions of till and B-horizon soil. Gold and As are enriched in all sample media (and in most size fractions) over a zone of glacial dispersal from the concealed mineralization. Appreciable enrichment of Sb occurs only in the spruce bark. Results show that either soil or spruce bark could be used to establish targets for more labour-intensive close-spaced sampling of heavy mineral concentrates in till.

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[1] Presented at 13th International Geochemical Exploration Symposium, Rio de Janeiro, September 1989

[2] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E8

COMPARATIVE SPATIAL ANALYSIS OF ANOMALIES DERIVED FROM BIOGEOCHEMICAL, LAKE SEDIMENT AND AIRBORNE GEOPHYSICAL DATA, EASTERN NOVA SCOTIA, CANADA[1]

H. George[3], G. F. Bonham-Carter[2], C. E. Dunn[2] and P. J. Rogers

Geographic information systems are increasingly being used to quickly prepare and display maps depicting various types of geoscience information, including data from multivariate geochemical and geophysical surveys. An issue which often arises when carrying out geological interpretations with such maps is whether or not anomalous patterns on pairs of maps are spatially associated.

This paper describes an investigation of this topic in an area of eastern Nova Scotia using three different data sets containing information obtained from non-common locations. These data sets are (i) balsam fir twig geochemistry (ii) centre-lake bottom sediment geochemistry and (iii) gamma-ray radiometrics. The first two data sets consist of element concentrations for Au, As and Th, the latter consists of equivalent thorium (eTh) estimated during an airborne geophysical survey.

Techniques for deriving binary anomalous patterns for each data set by successive thresholding and an approach for comparing the resulting maps by binary overlay are described. Three different measures, namely, (i) the proportion of anomaly overlap, O, (ii) the 'Weights of Evidence' contrast, C, and (iii) the conditional Kappa coefficient of agreement, K, are used to assess spatial associations between the binary patterns.

Results indicate positive spatial associations between anomalous patterns in the biogeochemical and centre-lake bottom sediment geochemical data for As. Spatial associations between Au in lake sediments and vegetation depend on the threshold used to define the anomalies; however, for Th, the association was consistently negative. Anomaly maps for As and Au exhibit overlap in several areas in which gold mineralization is known to occur. Low, generally positive spatial associations were also noted between maps of eTh and either lake sediment Th or balsam fir twig Th.

The technique for comparing maps by binary overlay is simple to carry out and relatively objective, therefore it can be of use in the interpretation of regional geoscience surveys.

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[1] Paper presented at GIS in the 90's symposium, Ottawa, Ontario, March 1990. In press, Journal of Geochemical Exploration.

[2] Mineral Resources Division, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E8

[3] Department of Geological Sciences, Queen's University, Kingston, Ontario, Canada K7L 3N6

GEOCHEMICAL MAPPING: COMPARISON OF REGIONAL LAKE SEDIMENT AND BIOGEOCHEMICAL SURVEYS, EASTERN SHORE, NOVA SCOTIA, CANADA[1]

P. J. Rogers, G. F. Bonham-Carter[2] and C. E. Dunn[2]

A case study has been conducted to compare geochemical patterns for gold and related elements in centre-lake bottom sediments and balsam fir twigs. The study area covers about 5,000 km^2 of the Eastern Shore region of Nova Scotia. The aim of this study is to investigate the application and feasibility of geochemical mapping in areas of multi-media sampling coverage with a view to developing an appropriate strategy for Appalachian and Canadian surficial geochemical conditions.

A microcomputer-based Geographic Information System, SPANS, Tydac Corporation Ltd., Ottawa, Ontario, was used to generate maps and model relationships between sample media, geological maps, mineral occurrences and elemental values. The regional lake sediment samples of organic-rich ooze, gyttja, were collected by gravity corers mounted on float equipped helicopters; the air dried samples were sieved and the -200 mesh fraction prepared for analysis. For the biogeochemical sampling the last five years growth of balsam fir were collected along available roads and tracks. The samples were dried in a microwave and ashed at 470°C with the fir needles removed prior to ashing. Both sample suites were analyzed by Instrumental Neutron Activation to facilitate comparison between surveys. Each survey had an approximate sampling density of 1 per 8 km^2 for a total of 650 biogeochemical and 436 lake sediment samples.

The study area is underlain by Meguma Zone (MZ) rocks which consist of Meguma Group (MG) metasediments of Cambro-Ordovician age. The lower turbidite sequence (Goldenville Formation) is conformably overlain by black slates (Halifax Formation). Structures in the MG are similar to those observed universally in slate belts. Deformation during the Acadian Orogeny produced tight to isoclinal, upright folds. Greenschist to amphibolite grade regional metamorphism was imposed during the Devonian Acadian Orogeny. Granitic bodies, sometimes of batholithic proportions, intruded the MG during the Acadian event. The South Mountain Batholith is the largest discrete intrusion in the MZ, although in the study area most of the intrusions are small in surface outcrop and are mainly located in the eastern part. Most of the significant Au deposits of Nova Scotia are found within the MG, especially in Goldenville Formation. The turbidite hosted Au deposits of the MG are typically native gold with arsenopyrite and carbonate in quartz veins. A series of NE trending anticlines and synclines form dome-like structures which are commonly associated with areas of Au enrichment. Recent work by Kontak and Smith (1988) also documents the presence of wide zones of silicic, carbonate and phyllic alteration around these deposits.

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[1] Abstracts of Papers and Poster on Geochemical Mapping presented at the International Geological Congress in Washington, D. C., July 10-12, 1989

[2] Geological Survey of Canada, Ottawa, Canada

Catchment Basin Analysis (CBA) was used to represent lake sediment data (Wright et al., 1988; Rogers, 1988) as an image whereas the biogeochemical data (Dunn, 1988) was interpolated as point data only. The spatial relationships between pairs of common elements were modelled by sampling the lake catchment basin map to "capture" any biogeochemical point locations within each catchment basin.

The response of each sampling medium to known mineralization and geologic controls is illustrated by maps of common elements. These maps indicate the degree of geochemical mobility and hence of partitioning between the sampling media. For lake sediments and biogeochemical samples there are strikingly similar patterns for some elements to offer encouragement to geochemical mapping. There are also sufficient differences to indicate geochemical mobility contrasts between the surveys. Of the shared elements As, Au, Rb, Sb, Th, W and Rb; the Au and As patterns are very similar for both media. The As plots highlight the known gold districts with anomalous values. A similar pattern exists for Au with geochemical highs over the deposits. For the other elements the lake sediment response is generally "flat" especially for Th, W, Rb and Sb. The biogeochemical maps are similarly unresponsive except for Rb and Sb which have a spatial relationship to major shear zones and granite contacts in the eastern half of the area. The common gold geochemical pattern was investigated by using the lake catchment basins to sample the biogeochemical point data. Using the SPANS package a map was produced for three coincident percentile intervals: the 90, 95 and 99th values. Both surveys have effectively sampled the major mineralization and have also generated shared anomalous areas.

The multivariate element patterns are more disparate and are probably reflecting the partitioning between media. In the lake sediments Wright et al. (1988) describe three principal components which are ascribed to the heavy mineral content, scavenging and the gold mineralisation. Factor analysis of the biogeochemical survey data also indicates a gold factor linked to Au, As, Sb, Ba and Ca distribution. The other factors link Au with Br and other elements in correlations not generally seen in the lake sediments.

This pilot study outlines shared geochemical patterns which are detectable in lake sediments and biogeochemical samples from Nova Scotia. Both media respond to the regional metallogeny and geological controls in similar and contrasting fashion. This is explained by contrasts in geochemical mobility in both media especially between point data such as biogeochemical, soils or tills and spatial data from lake or stream catchment basins. The integration of multimedia geochemical data is best achieved using Geographic Information Systems to compile shared patterns. The presence of distinct partitioning between sampling media such as point or spatial data types must be considered in a geochemical mapping exercise to obtain the most cost effective and efficient medium for global sampling.

REFERENCES

Dunn C. E., 1988. Reconnaisance level biogeochemistry surveys for gold in Canada. In: MacDonald D.R. and Mills K.A.(eds), Prospecting in Areas of

Glaciated Terrain 1988, CIM symposium, Halifax, Nova Scotia, August 28 - September 3, 1988, p. 433-448.

Rogers P. J., 1988. Gold in lake sediments: implications for precious metal exploration in Nova Scotia. In: MacDonald D.R. and Mills K.A.(eds), Prospecting in Areas of Glaciated Terrain 1988, CIM symposium, Halifax, Nova Scotia, August 28 - September 3, 1988, p. 357-382.

Wright D. F., Bonham-Carter G. F. and Rogers P. J., 1988. Spatial data integration of lake sediment geochemistry, geology and gold occurrences, Meguma Terrane, eastern Nova Scotia. In: MacDonald D.R. and Mills K.A.(eds), Prospecting in Areas of Glaciated Terrain 1988, CIM symposium, Halifax, Nova Scotia, August 28 - September 3, 1988, p. 501-516.

GEOCHEMICAL EXPLORATION USING MICRO-COMPUTER-BASED SYSTEMS WITH REFERENCE TO NOVA SCOTIA[1]

P. J. Rogers

Micro or personal computers (PCs) as laptops or desktops are now widely used in the field and office and have considerably aided productivity within the Nova Scotia Department of Mines and Energy. Prior to 1986, most computing was performed at considerable cost using dumb terminals connected via modems to remote mainframe computers. A consultant's study, commissioned in late 1985, indicated that the computing needs of the Department would be more economically met using IBM compatible (MS-DOS) PCs. The 2 fold strategy called for the initial acquisition of several stand alone PCs which would be networked later with a central minicomputer. With recent technological advances this latter strategy is now achieved with a central PC acting like the minicomputer networked to other intelligent terminals. In the Mineral Resources Division, the capital acquisition of PC hardware and software has cost $200,000, about half of which is for the Geochemistry Section. Experience with PCs since 1986 has demonstrated the absolute necessity of having an experienced programmer on staff plus the need for a considerable on-going training commitment. Experienced computer users are given responsibility for a PC as the "systems operator". In-house seminars are given by computer literate staff members to train other personnel which represents considerable savings on external computer courses. Savings can also be made by systems operators performing routine maintenance such as cleaning printers, keyboards and computers. In the Mineral Resources Division approximately 30 geologists use the available PCs on a time shared basis of 3 geologists per workstation.

In the Geochemistry Section a database from various surficial media has been compiled from several regional geochemical surveys. These surveys, at an average sampling density of 1 per $5/km^2$, are designed to stimulate exploration activity by defining appropriate targets for the private sector and also investigate the chemical composition of surficial materials in Nova Scotia. These data include lake, stream sediments and waters; soils; tills and vegetation samples.

The section has a central 386 PC desktop and a laptop Toshiba 286 PC for recording field observations. Peripheral devices include a dot matrix printer, pen plotter and laser plotter which are used to produce reports and maps up to 11 x 17". Application software includes: WordPerfect (word processing), Revelation (database), Lotus 1-2-3 (spreadsheet), Systat and Statgraphics (statistics). Most of these packages are used at various stages of file editing, manipulation and report preparation.

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[1] Presented at Computer Applications in Mineral Exploration Symposium, March 9-10, 1990, Toronto, Canada

The use of PCs in mineral exploration will be illustrated by three case studies: lake sediments for gold exploration, soil and stream sediment sampling for base metals. About 90% of all computing activity is devoted to the (essential) drudgery of data vetting, file manipulation and quality control. Most of this is achieved through special macros written in DATAMINE/GX, the geochemical 'work horse' graphical/database program. Data analysis normally proceeds through a series of steps which always commences with basic statistics and plotting of cumulative frequency curves for each element of interest. Different populations are defined from breaks in the frequency curve for each element. Area maps of proportional symbols are plotted for each element in addition to histograms and population maps. The soil data example from northern Nova Scotia indicates an unsuspected NW trend for Cu, Pb, Zn and Ag anomalies when they are plotted as discrete populations. After these basic univariate statistical tests are applied correlation matrices are developed. An example of multivariate analysis using principal components illustrates anomaly enhancement of stream sediment data to indicate precious metal potential, which was confirmed by a later survey.

The SPANS GIS package allows rapid data analysis using the area calculation, modelling, unique conditions and potential mapping facilities. GIS such as SPANS are used to plan sampling design, estimate different background levels for geological units and integrate airborne geophysics, satellite imagery such as SAR, TM and SPOT with the surficial geochemistry. Examples of regional stream and lake sediment survey data treated in this way are presented which indicate new potentially mineralized areas for base metals and gold.

Microcomputers play an essential role in the treatment of exploration geochemical data. Advantages include low cost when compared to remote mainframes, ease of use and ready availability to staff. The disadvantages are understanding the often complex and conflicting interactions between differing software, hardware and peripheral output devices which can consume a lot of effort. Experience has shown that computer literate person will find it relatively easy to learn new software packages, however a wide variance in computer literacy is found among staff geologists. Training is accelerated with a staff programmer coupled with lots of in-house seminars. The personal side of the computer equation also presents problems when faced with the choice of the multitude of commercial software packages available today, most of which have overlapping functionality. Several issues such as these will be discussed in light of the Nova Scotia experience.

APPENDIX I

NOVA SCOTIA DEPARTMENT OF MINES AND ENERGY PUBLICATIONS AND MAPS AVAILABLE FOR PURCHASE

PAPERS

Paper 76-1	Structural Model for the Saddle Reef and Associated Veins in the Meguma Group, Nova Scotia, by J. D. Keppie, 34 pages, 2 maps. ($3.00)
Paper 76-2	Geological Data Collection in the Nova Scotia Department of Mines, by J. D. Keppie and A. K. Chatterjee, 15 pages. ($0.50)
Paper 76-3	Interpretation of P.P.I. Radar Imagery of Nova Scotia, by J. D. Keppie, 31 pages, 1 map. ($1.25)
Paper 76-4	Geology, Geochemistry and Mineral Occurrences of the Northeast Margaree River Drainage Basin in parts of Inverness and Victoria Counties, Cape Breton, Nova Scotia, by B. E. MacNabb, J. H. Fowler and T. G. N. Covert, 30 pages, 12 maps. ($15.00)
Paper 76-5	Guide to the Invertebrate Fauna of the Windsor Group in Atlantic Canada, by R. G. Moore and R. J. Ryan, 57 pages. ($2.25)
Paper 77-1	Tectonics of Southern Nova Scotia, by J. D. Keppie, 34 pages (Reprinted 1980). ($3.00)
Paper 77-3	Plate Tectonic Interpretation of Paleozoic World Maps (with Emphasis on Circum-Atlantic Orogens and Southern Nova Scotia), by J. D. Keppie, 45 pages (Reprinted 1982). ($4.00) (Microfiche $1.50)
Paper 77-6	Sand and Gravel Resources of Pictou County, by J. H. Fowler and G. B. Dickie, 42 pages, 1 map. ($4.00)
Paper 77-7	Tungsten Mineralization in the Carbonate Rocks of the George River Group, Cape Breton Island, Nova Scotia, by A. K. Chatterjee, 26 pages. ($3.50)
Paper 78-1	Geology of the Ecum Secum Area, Halifax and Guysborough Counties, Nova Scotia, by D. McBride, 12 pages. ($1.00)
Paper 78-2	Age of Igneous Rocks along the Lennox Passage - St. Peter's Lineament, Southern Cape Breton Islands, by J. D. Keppie and P. K. Smith, 10 pages. ($1.00)
Paper 78-3	Geology of the Giant Lake Area, Southeastern Cape Breton Island, Nova Scotia, by P. K. Smith, 30 pages, 1 map. ($2.00)
Paper 78-4	Some Middle Devonian to Lower Carboniferous Rocks of Cape George, Nova Scotia, by J. D. Keppie, P. S. Giles, and R. C. Boehner, 37 pages. ($2.00)
Paper 78-5	Petrology of the Early Silurian Dunn Point and McGillivray Brook Formations, Arisaig, Nova Scotia, by J. D. Keppie, J. Dostal and M. Zentilli, 20 pages. ($1.00)
Paper 79-1	Petrology of the Late Precambrian Fourchu Group in the Louisbourg Area, Cape Breton Island, by J. D. Keppie, J. Dostal and J. B. Murphy, 18 pages. ($1.50)
Paper 79-2	Opencast Coal Reserves at Springhill, by B. Ward, 40 pages, 4 maps. ($4.50)
Paper 79-3	Geology of the Meat Cove Zinc Deposit, Cape Breton Island, by A. K. Chatterjee, 27 pages. ($2.00)
Paper 79-4	Minor and Trace Element Variations in Wisconsinan Tills, Eastern Shore Region, Nova Scotia, by R. R. Stea and J. H. Fowler, 30 pages, 3 maps. ($10.00)
Paper 79-5	Pleistocene Stratigraphy of the Miller Creek Section, Hants County, Nova Scotia, by R. Stea and D. Hemsworth, 16 pages. ($3.00)
Paper 79-6	Effects of Subsidence and Depositional Environment on the Formation of Lithotypes in a Hypautochthonous Coal of the Pictou Coalfield, by J. H. Calder, 23 pages. ($3.00)
Paper 79-7	Carbonate Banks of the Gays River

	Formation in Central Nova Scotia, by P. S. Giles, R. C. Boehner and R. J. Ryan, 57 pages, 1 map. ($4.00)
Paper 80-1	Geology of the Cape North Area, Northern Cape Breton Island, Nova Scotia, by A. S. Macdonald and P. K. Smith, 60 pages, 2 maps. ($5.00) (Microfiche $2.00)
Paper 81-1	The Fisset Brook Formation at Lowland Cove, Inverness County, Nova Scotia, by P. K. Smith and A. S. Macdonald, 18 pages. ($2.00) (Microfiche $1.00)
Paper 81-2	Major Transgressive-Regressive Cycles in Middle to Late Viséan Rocks of Nova Scotia, by P. S. Giles, 27 pages. ($2.00) (Microfiche $1.50)
Paper 81-3	The Windsor Group of the Mahone Bay Area, Nova Scotia, by P. S. Giles, 51 pages, figure in back pocket. ($4.00) (Microfiche $1.50)
Paper 81-4	Principles of Tectonic Mapping Based upon Plate Tectonic Theory, by J. D. Keppie, 11 pages. ($1.50) (Microfiche $1.00)
Paper 82-1	Geology and Geochemistry of Selected Granitoid Plutons of Cape Breton Island, by S. M. Barr, G. A. O'Reilly and A. M. O'Beirne, 176 pages, 44 figures, 13 tables. ($8.00) (Microfiche $2.00)
Paper 82-2	Metasomatic-Hydrothermal Mineral Deposits of the New Ross-Mahone Bay Area, Nova Scotia, by G. A. O'Reilly, E. J. Farley and M. H. Charest, 96 pages. ($5.00) (Microfiche $1.50)
Paper 84-1	Petrology of Granitoid Rocks of the Boisdale Peninsula, Central Cape Breton Island, Nova Scotia, by S. M. Barr and J. R. D. Setter, 1986, 75 pages, includes Nova Scotia Department of Mines and Energy Map 84-2 folded in back pocket. ($8.00) (Microfiche $2.00)
Paper 85-2	The formation of veins in greenschist facies rocks and the early deformation of the Meguma Group, Eastern Nova Scotia, by B. H. O'Brien, 1985, 35 pages. ($3.00) (Microfiche $1.00)
Paper 86-1	Cretaceous Deposits of Nova Scotia, by G. B. Dickie, 1987, 54 pages. ($15.00) (Microfiche $3.00)
Paper 89-1	Metallogenic Studies of Southeastern Cape Breton Island, by A. S. Macdonald, 1989, 99 pages, 3 figures in pocket. ($20.00) (Microfiche $3.00)
Paper 89-2	Geology of the Mabou Highlands, by S. M. Barr and A. S. Macdonald, 1989.
Paper 89-3	Re-evaluation of the Coal Resources of Western Cape Breton Island, by P. A. Hacquebard, K. S. Gillis and D. S. Bromley, 1989.

REPORTS

Report 75-1	Report of Activities of the Mineral Resources and Geological Services Division, 1974, by Nova Scotia Department of Mines, 75 pages. ($1.00)
Report 76-1	Drilling Logs of Government Core Drills, 1974, by I. MacDougall and D. W. Grimm, 73 pages. ($1.00)
Report 76-2	Mineral Resources Division, Report of Activities, 1975, 145 pages. ($3.00)
Report 76-3	Drilling Logs of Government Core Drills, 1975, by I. MacDougall and D. W. Grimm, 47 pages. ($1.00)
Report 77-1	Mineral Resources Division, Report of Activities, 1976, 207 pages. ($10.00)
Report 77-2	Superseded by Report 81-4.
Report 77-3	Drilling Logs of Government Core Drills, 1976, by I. MacDougall and D. W. Grimm, 33 pages. ($1.00)

Report 78-1	Mineral Resources Division, Report of Activities, 1977, 104 pages. ($4.00)
Report 78-2	Drilling Logs of Government Core Drills, 1977, by I. MacDougall and D. E. Polley, 72 pages. ($2.00)
Report 78-3	Superseded by Report 81-6.
Report 78-4	Compilation of Isotopic Age Data of Nova Scotia, by J. D. Keppie and P. K. Smith, 54 pages, 7 maps. ($7.00)
Report 79-1	Mineral Resources Division, Report of Activities, 1978, 177 pages. ($6.00)
Report 79-2	Drilling Logs of Government Core Drills, 1978, by I. MacDougall and D. E. Polley, 54 pages. ($2.00)
Report 80-1	Mineral Resources Division, Report of Activities, 1979, 248 pages. ($7.00)
Report 80-2	Index to Drilling Logs of Government Core Drills, 1972-78, by N. A. Lyttle and J. Gillespie-Wood, 47 pages. ($3.00)
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CS 90-001	Fluorescence Properties of Alginite-rich Oil Shales from the Stellarton Basin, Canada, by W. Kalkreuth, R. Naylor, K. Pratt and W. Smith. Reprinted from Fuel, v. 69, February 1990, p. 139-144. (No Microfiche)

ECONOMIC GEOLOGY SERIES

EGS 74-1	Geology and Trace Elements of Nova Scotia Manganese Occurrences in Nova Scotia, by D. G. Bishop and J. D. Wright, 1974, 255 pages. ($7.50)
EGS 75-1	Iron Deposits of Nova Scotia, by J. D. Wright, 1975, 154 pages, 1 map. ($6.00)
EGS 89-1	Properties and Uses of Nova Scotia Clays and Shales, by Susan Gouthro, 1989, 288 pages. ($20.00) (Microfiche $3.00)
EGS 90-1	Diatomaceous Earth Occurrences in Nova Scotia, by A. R. Anderson, 1990, 132 pages. ($15.00) (Microfiche $3.00)
EGS 90-2	Fillers and Extender Minerals in Nova Scotia, by Peter Luke, 1990, 64 pages. ($6.00) (Microfiche $2.00)

MISCELLANEOUS PUBLICATIONS

MP 58-2	Possibilities for Occurrence of Petroleum Reservoirs in Nova Scotia, by W. A. Bell, 1958, 177 pages. ($1.00)
MP 59-1	Drilling Logs of Government Core Drills, 1958, by M. G. Goudge and D. M. MacLeod, 34 pages. ($1.00)
MP 60-1	Drilling Logs of Government Core Drills, 1959, by M. G. Goudge and D. M. MacDonald, 38 pages. ($1.00)
MP 61-1	Drilling Logs of Government Core Drills, 1960, by C. F. Townsend and D. M. MacLeod, 33 pages. ($1.00)
MP 62-1	Drilling Logs of Government Core Drills, 1961, by C. F. Townsend and D. M. MacLeod, 49 pages. ($1.00)
MP 63-1	Drilling Logs of Government Core Drills, 1962, by C. F. Townsend and D. M. MacLeod, 35 pages. ($1.00)
MP 64-1	Drilling Logs of Government Core Drills, 1963, by C. F. Townsend

	and D. W. Grimm, 36 pages. ($1.00)
MP 65-1	Drilling Logs of Government Core Drills, 1964, by C. F. Townsend and D. W. Grimm, 43 pages. ($1.00)
MP 66-1	Drilling Logs of Government Core Drills, 1965, by C. F. Townsend and D. W. Grimm, 55 pages. ($1.00)
MP 66-2	Metallic Mineral Occurrences Recorded in the Province of Nova Scotia, by Nova Scotia Department of Mines, 1966, 350 pages. ($4.00)
MP 67-1	Drilling Logs of Government Core Drills, 1966, by C. F. Townsend and D. W. Grimm, 27 pages. ($1.00)
MP 68-1	Drilling Logs of Government Core Drills, 1967, by C. F. Townsend and D. W. Grimm, 39 pages. ($1.00)
MP 68-2	Core Drilling in Nova Scotia with Government Drills, 1871-1966, 176 pages. ($2.00)
MP 69-1	Drilling Logs of Government Core Drills, 1968 by C. F. Townsend and D. W. Grimm, 58 pages. ($1.00)
MP 69-2	Handbook for Companies Planning Offshore Drilling, by Nova Scotia Department of Mines, 1969, 23 pages. ($.50)
MP 70-1	Drilling Logs of Government Core Drills, 1969, by C. F. Townsend and D. W. Grimm, 65 pages. ($1.00)
Mp 71-1	Drilling Logs of Government Core Drills, 1970, by C. F. Townsend and D. W. Grimm, 71 pages. ($1.00)
MP 72-1	Drilling Logs of Government Core Drills, 1971, by C. F. Townsend and D. W. Grimm, 81 pages. ($1.00)
MP 72-2	Clay and Sand Deposit at Elmsvale, Halifax County, Nova Scotia, by J. H. Fowler, 1972, 62 pages & drillhole sections. ($2.50)
MP 72-3	Geology of the Middle River and Baddeck Forks Map Areas, Victoria County, Nova Scotia, by B. E. Jones and T. G. N. Covert, 1972, 124 pages and 5 maps. ($5.00)
MP 75-1	Drilling Logs of Government Core Drills, 1972, by I. MacDougall and D. W. Grimm, 85 pages. ($1.00)
MP 75-2	Drilling Logs of Government Core Drills, 1973, by I. MacDougall and D. W. Grimm, 76 pages. ($1.00)

NOTE: Drilling logs after 1973 are published as part of the Report series.

MP 75-3	Core Drilling in Nova Scotia with Government Drills, 1967-1971, 49 pages. ($1.00)
MP 75-4	Bibliography of the Geology of Nova Scotia, by D. J. Gregory, 1975, 237 pages. (Microfiche $4.00)
MP 84-1	Nova Scotia Oil and Gas Report 1984. ($2.00)
MP 84-2	An Introduction to the Offshore, 1984, 19 pages. (Free)
MP 85-1	Nova Scotia Oil and Gas Report 1985. ($2.00)
MP 87-1	Nova Scotia Oil and Gas Report 1987. ($2.00)
MP 88-1	Nova Scotia Oil and Gas Report 1988. ($2.00)
MP 88-2	Industrial Mineral Mining in Nova Scotia: Proud Tradition, Bright Future, 1988. (Free)

ACTS

Mineral Resources Act, by Nova Scotia Department of Mines and Energy, 1975, 61 pages. ($1.50)

Regulations under the Mineral Resources Act, 1975,

- Work on Mineral Rights, 4 pages. ($0.25)

- Boundaries of Mineral Lands, 4 pages. ($0.25)
- Schedule of Fees, 1 page. ($0.25)
- Royalties, 1 page. ($0.25)

Coal Mines Regulation Act, by Nova Scotia Department of Mines and Energy, 1967, 143 pages. ($3.00)

Petroleum Resources Act, by Nova Scotia Department of Mines and Energy, 1984. ($0.75)

Gypsum Mining Income Tax Act cited as R.S.N.S., 1967, Chapter 122, 1979, 9 pages. ($1.00)

An Act Respecting Exploration for the Underground Storage of Gas, by Nova Scotia Department of Mines and Energy, 1970, 6 pages. ($1.00)

MAPS

Preliminary Map 78-1 Geology Map of the Cobequid Highlands, by H. V. Donohoe and P. I. Wallace, scale 1:125 000. ($3.50)

Map 81-1	Pleistocene Geology and Till Geochemistry, Central Nova Scotia, (Sheet 4) by R. R. Stea and J. H. Fowler, scale 1:100 000 (Sheets 1, 2 and 3 are in Paper 79-4). ($3.50)
Map 82-1	Pleistocene Geology and Till Geochemistry of South Central Nova Scotia (Sheet 6), by R. R. Stea, scale 1:100 000 (Sheet 5 is in OFR 555). ($3.50)
Map 82-2	Antigonish Basin, by R. C. Boehner and P. S. Giles, scale 1:50 000. ($3.00)
Map 82-3	Eureka Area, by P. S. Giles, scale 1:50 000. ($3.00)
Map 82-4	Shubenacadie and Musquodoboit Basins, by P. S. Giles and R. C. Boehner, scale 1:50 000. ($5.00)
Map 82-5	Geology Map of the Northern Antigonish Highlands, Nova Scotia, by J. B. Murphy, J. D. Keppie and A. Hynes, scale 1:50 000. ($4.00)
Map 82-6[1]	Advocate Harbour-Port Granville Region, by H. V. Donohoe, Jr. and P. I. Wallace, scale 1:50 000. ($8.00)
Map 82-7[1]	Parrsboro-Five Islands Region, by H. V. Donohoe, Jr. and P. I. Wallace, scale 1:50 000. ($8.00)
Map 82-8[1]	Economy River-Folly Lake Region, by H. V. Donohoe, Jr. and P. I. Wallace, scale 1:50 000. ($8.00)
Map 82-9[1]	Debert-Mt. Thom Region, by H. V. Donohoe, Jr. and P. I. Wallace, scale 1:50 000. ($8.00)
Map 82-10	Pleistocene Geology and Till Geochemistry of Southwestern Nova Scotia (Sheets 7 and 8), by R. R. Stea and D. R. Grant 1:100 000. (Sheet 9 is in GSC Paper 85-17). $8.00)
Map 83-1	Geological Map of the Hantsport Area, Nova Scotia, compilation and geology of S. A. Ferguson, scale 1:25 000. ($5.00)
Map 83-2	Calculated Vertical Magnetic Gradient Map of the Cape Breton Highlands, Inverness, and Victoria Counties, Nova Scotia, scale 1:125 000. ($5.00)
Map 83-3	Salt and Potash Resources of Nova Scotia, by R. C. Boehner, scale 1:500 000. ($4.00)
Map 83-4	Geological Map of the Red River Anorthosite Complex, Inverness and Victoria Counties, Nova Scotia, by P. K. Smith and A. S. Macdonald, scale 1:125 000. ($1.50)
Map 84-1	Geological Map of the Cochrane Hill Open-Pit Gold Deposit, Guysborough County, Nova Scotia, by P. K. Smith, scale 1:66.7. ($8.00)
Map 84-2	Geological Map of the Boisdale Peninsula, Central Cape Breton Island, Cape Breton County, Nova Scotia, by S. M. Barr and

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[1] NOTE: Maps 82-6 to 82-9 may be purchased individually or as a set for $25.00

	J. R. D. Setter, 1984, scale 1:100 000. ($4.00)
Map 85-1	Industrial mineral commodities map of the Province of Nova Scotia, by J. H. Fowler, 1985, scale 1:500 000. ($5.00)
Map 85-2	Loch Lomond Basin and Glengarry Half Graben by R. C. Boehner and G. Prime, scale 1:50 000. ($5.00)
Map 85-3[2]	Aggregate Resources, Cape Breton Island by W. J. Wright, scale 1:125 000 (locates and names aggregate pits and quarries). ($3.00)
Map 85-4[2], 85-5[2] and 85-6[2]1:	Aggregate Resources, Cape Breton Island, by W. J. Wright, scale 125 000 (locates and gives the type, quality and observed thickness of sand and gravel deposits). ($3.00 each)
Map 86-1	Geological map of the Sydney Basin, Cape Breton Island, Nova Scotia; by R. C. Boehner and P. S. Giles, 1986, scale 1:50 000. ($5.00)
Map 86-2	Geological map of the Windsor area, Nova Scotia, by R. G. Moore and S. A. Ferguson, 1986, scale 1:25 000. ($5.00)
Map 87-1	Glacial Geology Map of Mount Uniacke (11D/13 West), by P. W. Finck and R. M. Graves, 1987, scale 1:500 000. ($6.00)
Map 87-2	Glacial Geology Map of Halifax and Sambro (11D/12 and 11D/05), by P. W. Finck and R. M. Graves, 1987, scale 1:50 000. ($6.00)
Map 87-3	Till Clast and Simplified Glacial Geology Map of Mount Uniacke (11D/13 West), by R. M. Graves and P. W. Finck, 1987, scale 1:50 000. ($6.00)
Map 87-4	Till Clast and Simplified Glacial Geology Map of Halifax-Sambro (11D/12 and 11D/05), by R. M. Graves and P. W. Finck, 1987, scale 1:50 000. ($6.00)
Map 87-6	Bedrock geological map of Halifax and Sambro (11D/12 and 11D/05), by M. A. MacDonald and R. J. Horne, 1987, scale 1:50 000. ($6.00)
Map 87-7	Bedrock geological map of Windsor (21A/16 East), by L. J. Ham and R. J. Horne, 1987, scale 1:50 000. ($6.00)
Map 87-8	Bedrock geological map of Mount Uniacke (11D/13 West), by M. C. Corey, 1987, scale 1:50 000. ($6.00)
Maps 88-13 to 88-14	Surficial Geology of Parts of and Colchester, Cumberland, Pictou and Hants Counties, Nova Scotia (Sheets 10 and 11), by R. R. Stea and P. W. Finck, 1988, scale 1:100 000. ($8.00)
Map 89-1	The Peatland Areas of Nova Scotia, 1986, by A. R. Anderson and W. A. Broughm, sheet 1, scale 1:250 000. ($3.00)
Map 89-2	The Peatland Areas of Nova Scotia, 1986, by A. R. Anderson and W. A. Broughm, sheet 2, scale 1:250 000. ($3.00)
Map 89-3	The Peatland Areas of Nova Scotia, 1986, by A. R. Anderson and W. A. Broughm, sheet 3, scale 1:250 000. ($3.00)
Map 90-1	Geology of the Canadian Salt Company Limited, Pugwash Mine (11E/13A), 630 level, Pugwash, Nova Scotia, by D. C. Carter, 1990, scale 1:1600. ($5.00)
Map 90-2	Geology of the Canadian Salt Company Limited, Pugwash Mine (11E/13A), 730 level, Pugwash, Nova Scotia, by D. C. Carter, 1990, scale 1:1600. ($5.00)
Map 90-3	Geology of the Canadian Salt Company Limited, Pugwash Mine (11E/13A), 830 level, Pugwash, Nova Scotia, by D. C. Carter, 1990, scale 1:1600. ($5.00)

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[2] NOTE: Maps 85-3 to 85-6 may be purchased individually or as a set for $10.00

Map 90-4	Till clast and glacial geology of Chester (21A/09), Nova Scotia, by R. M. Graves and P. W. Finck, 1990, scale 1:50 000. ($11.00)

Geological Map of Nova Scotia, by J. D. Keppie, scale 1:500 000, 1979, with metamorphic and structural map inserts, by J. D. Keppie and G. K. Muecke, scale 1:1 000 000. ($2.50)

Geological Map of Nova Scotia, Metallic Mineral Occurrence Edition, by J. D. Keppie, D. J. Gregory, A. K. Chatterjee and N. A. Lyttle, scale 1:500 000, with structural and metamorphic map inserts by J. D. Keppie and G. K. Muecke, 1979, scale 1:1000 000. ($2.50)

Geological Map of Nova Scotia, Bouger Gravity Anomaly Edition, by J. D. Keppie, scale 1:500 000, with metamorphic and structural map inserts by J. D. Keppie and G. K. Muecke, 1979, scale 1:1 000 000. ($2.50)

Tectonic Map of Nova Scotia, by J. D. Keppie, 1982, scale 1:500 000. ($5.00)

Metallogenic Map of Nova Scotia, by A. K. Chatterjee, 1983, scale 1:500 000. ($5.00)

Folio of Geological Maps of Nova Scotia - includes Geological, Structural, Metamorphic, Classes of Mineral Deposits, Bouguer Gravity Anomaly and Magnetic Maps, by J. D. Keppie, G. K. Muecke, A. K. Chatterjee and others, 1979, scale 1:2 000 000. ($1.00)

Geological Highway Map of Nova Scotia by J. P. Bujak and H. V. Donohoe, Jr., 1980, scale 1:633 600. (Atlantic Geoscience Society, Special Publication Number 1). ($3.50)

A Map Book of the Province of Nova Scotia, scale 1:250 000, revised edition 1985 with index of geographical names, 39 pages. ($9.00)

A Map Book of the Province of Nova Scotia, Geological Edition, scale 1:250 000, 1979, 46 pages. ($10.00)

Claims maps (compilation) of Nova Scotia, scale 1:500 000 (1 white print). ($5.00)
Reservation Grid System for Petroleum Licences, Onshore, scale 1:500 000 (1 white print). (Free)

Reservation Grid System for Petroleum Licences, Offshore, scale 1:1 500 000 (1 white print). (Free)

OPEN FILE MAPS

The following Open File Maps are available for purchase from the Library as white print copies. Exceptions are indicated.

OFM 85-01	Thesis study locations in Nova Scotia, compiled by D. B. Hopper, D. R. MacDonald and D. A. Wilkinson, scale 1:500 000, 1985. ($3.00)
OFM 86-049 to 86-056	Gold compilation of the Meguma Terrane in Nova Scotia, by J. McMullin, G. Richardson, T. Goodwin, 8 maps, scale 1:100 000. (copies available from Precision Microfilming Services Ltd., 6100 Young Street, Halifax, Nova Scotia B3K 2A4, (902) 455-5451).
OFM 87-004	Preliminary geology map, New Germany (21A/10), by R. Horne, scale 1:50 000. ($2.00)
OFM 88-001 to 88-012	Mineral Resource land use maps for Halifax County, by D. B. Hopper and C. A. Dobson, 1988, 12 maps, scale 1:50 000. ($2.00 per map)
OFM 88-013	Preliminary geological map of Chester (21A/09), by M. C. Corey, scale 1:50 000. ($2.00)
OFM 88-014	Glacial and Till Clast Geology of the Windsor Map Sheet (21A/16), South Mountain Batholith Project, by P. W. Finck, R. M. Graves, F. J. Boner and H. G. Bent, scale 1:50 000. ($2.00)
OFM 88-015	Preliminary geological map of Windsor (21A/16) West Half and part of (21H/01), by L. J. Ham, scale 1:50 000. ($2.00)
OFM 88-016	Preliminary geological map of Gaspereau Lake (21A/15) and part of 21H/02), by M. A. MacDonald and L. J. Ham, scale 1:50 000. ($2.00)
OFM 88-017 to 88-022	Mineral resource land use maps for Hants County, by D. B. Hopper and H. J. Gillis, 1988, 6 maps, scale 1:50 000. ($2.00, $12.00 set)
OFM 88-024	Geological map of New Minas-Canaan

Quadrangle, compiled by Dr. Stewart A. Ferguson 1976-1978, 1985-1987, scale 1:10 000. ($2.00)

OFM 88-031	Till geochemistry map, Pictou and Antigonish Counties (sheet 12), by R. G. Turner and R. R. Stea, scale 1:100 000. ($2.00)
OFM 88-032	Till geochemistry map, northern mainland Nova Scotia, heavy mineral separate analyses (sheet 12), by R. G. Turner and R. R. Stea, scale 1:100 000. ($2.00)
OFM 88-033 to 88-038	Mineral resource land use maps for Cape Breton County, by D. B. Hopper and H. J. Gillis, 1988, 6 maps, scale 1:50 000. ($2.00, $12.00 set)

NOTE: OFM 88-39 to 88-043 are available for viewing at the NSDME library or for purchase from Precision Microfilming Services Ltd., 6100 Young Street, Halifax, Nova Scotia, B3K 2A4 (455-5451).

OFM 88-039	Preliminary geological maps of the Cumberland Basin, Tatamagouche and Oxford (11E/11 and 11E/12), by R. J. Ryan, R. C. Boehner and A. Deal, 23 maps, scale 1:10 000.
OFM 88-040	Preliminary geological maps of the Cumberland Basin, Pugwash and Malagash (11E/13 and 11E/14), by R. J. Ryan, R. C. Boehner and A. Deal, 21 maps, scale 1:10 000.
OFM 88-041	Preliminary geological maps of the Cumberland Basin, Cape Chignecto and Parrsboro (21H/07 and 21H/08), by A. Deal, R. J. Ryan and R. C. Boehner, 13 maps, scale 1:10 000.
OFM 88-042	Preliminary geological maps of the Cumberland Basin, Springhill and Apple River (21H/09 and 21H/10), by R. J. Ryan, A. Deal, J. H. Calder and R. C. Boehner, 24 maps, scale 1:10 000.
OFM 88-043	Preliminary geological maps of the Cumberland Basin, Amherst, (21H/16), by R. C. Boehner, R. J. Ryan and A. Deal, 11 maps, scale 1:10 000.
OFM 88-044 to 88-049	Mineral Resource Land Use Maps for Kings County (21A/10, 21A/15, 21A/16, 21H/01, 21H/01, 21H/02, 21H/08), by D. B. Hopper and H. J. Gillis, scale 1:50 000. ($2.00, $12.00 set).
OFM 88-050	Till Geochemistry of Northern Mainland Nova Scotia Clay Fraction Analyses, Antigonish and Guysborough Counties (Map Sheet 13-88), by R. G. Turner and R. R. Stea, scale 1:00 000. ($2.00)
OFM 88-051	Till Geochemistry of Northern Mainland Nova Scotia Heavy Mineral Separate Analyses, Antigonish and Guysborough Counties (Map Sheet 13-88), by R. G. Turner and R. R. Stea, scale 1:100 000. ($2.00)
OFM 89-001	Geological Map of Kentville-South Alton Quadrangle, compiled by S. A. Ferguson, 1987-1988, scale 1:10 000. ($2.00)
OFM 89-002	Geological Map of West Gore Quadrangle, by R. G. Moore, 1988, scale 1:10 000. ($2.00)
OFM 89-003	Geological Map of Newport Corner Quadrangle, by R. G. Moore, 1988, scale 1:10 000. ($2.00)
OFM 89-005 to 89-009	Mineral Resource Land Use Maps for Lunenburg County, by D. B. Hopper and H. J. Gillis, 1989, 5 maps, scale 1:50 000 ($10.00 (set); $2.00 per map)
OFM 89-010	Preliminary Geological Map of Lake Rossignol (21A/03W), by M. C. Corey and R. J. Horne, scale 1:50 000. ($2.00)
OFM 89-012	Preliminary Geological Map of Weymouth (21A/05), by M. A. MacDonald and L. J. Ham, scale 1:50 000. ($2.00)
OFM 89-014	Preliminary Geological Map of Milford (21A/11), by M. C. Corey and R. J. Horne, scale 1:50 000. ($2.00)
OFM 89-015	Preliminary Geological Map of Digby (21A/12), by L. J. Ham, scale 1:50 000. ($2.00)

OFM 89-016	Preliminary Geological Map of Bridgetown (21A/14), by M. A. MacDonald and L. J. Ham, scale 1:50 000. ($2.00)
OFM 89-017	Geological Map of the Stellarton Basin (West Half) Pictou County, Nova Scotia, by W. D. Smith, K. S. Gillis, S. A. Montgomery, scale 1:5 000. ($2.00)
OFM 89-018	Preliminary Glacial Geology of the South Mountain Batholith, Western Nova Scotia, South Mountain Batholith Project, by P. W. Finch, R. M. Graves and F. J. Boner, scale 1:250 000. ($2.00)
OFM 89-019	Preliminary Glacial and Till Clast Geology of the New Germany Map Sheet (21A/10), South Mountain Batholith Project, by P. W. Finck, R. M. Graves and F. J. Boner, scale 1:50 000. ($2.00)

OPEN FILE REPORTS

The following Open File Reports are available for purchase from the Library in hard copy. Microfiche copies may be purchased from Precision Microfilming Services, 6100 Young Street, Halifax, Nova Scotia B3K 2A4.

OFR 329	The Glencoe Limestone and Dolomite Survey, by D. J. MacNeil, 1977, 252 pages, 12 maps. ($15.00)
OFR 599	Metallic Mineral Occurrences Map and Data Compilation, Central Nova Scotia - map sheets 11D and 11E by M. Ponsford and N. A. Lyttle, 1984, 21 pages, 2 maps. ($3.00)
OFR 600	Metallic Mineral Occurrences Map and Data Compilation, Eastern Nova Scotia - map sheets 11F, 11G, 11J, 11K, 11N, by M. Ponsford and N. A. Lyttle, 1984, 23 pages, 2 maps. ($3.00)
OFR 601	Metallic Mineral Occurrences Map and Data Compilation, Western Nova Scotia - map sheets 20O, 20P, 21A, 21B, 21H, by M. Ponsford and N. A. Lyttle, 1984, 21 pages, 2 maps. ($3.00)
OFR 603	Preliminary Feasibility Study for an Underground Gold Mining Operation in Central Nova Scotia, by Nova Scotia Department of Mines and Energy, 1984, 62 pages, 2 maps. ($5.00)
OFR 605	Regional Lake Sediment Survey of the Meguma Zone, Southern Nova Scotia: New Analytical Data, by P. J. Rogers, M. A. MacDonald and D. W. Rigby, 1985, 65 pages, 2 maps. ($5.00)
OFR 606	Industrial Mineral Occurrences Map and Data Compilation, Central Nova Scotia - map sheets 11D, 11E by M. Ponsford, G. DeMont and N. A. Lyttle, 1985, 22 pages, 2 maps. ($4.00)
OFR 607	Industrial Mineral Occurrences Map and Data Compilation, Eastern Nova Scotia - map sheets 11F, 11G, 11J, 11N, by M. Ponsford, G. DeMont and N. A. Lyttle, 1985, 29 pages, 2 maps. ($4.00)
OFR 608	Industrial Mineral Occurrences Map and Data Compilation, Western Nova Scotia - map sheets 20O, 20P, 21A, 21B, 21H, by M. Ponsford, G. Demont and N. A. Lyttle, 1985, 21 pages, 2 maps. ($4.00)
OFR 621	Effects of Location on Mine Development Potential: Nova Scotia's Competitive Position in Canada, by D. W. Davis, B. W. MacKenzie and M. L. Bilodeau, 1985, 103 pages. ($15.00)
OFR 648	Current Market Economics of the Strontium Minerals by Metals Economic Group of Halifax, Nova Scotia and Boulder, Colorado, 1985, 54 pages. ($5.00)
OFR 650	Preprint of Paper 85-3. Guide to the Granites and Mineral Deposits of Southwestern Nova Scotia, edited by A. K. Chatterjee and D. B. Clarke, 1985, 264 pages. ($15.00)
OFR 651	Gypsum property, Ownership and Leases, by M. W. G. King, 1985, 140 pages. ($10.00)
OFR 656	The Development Potential for Nova Scotia's Offshore Aggregate and Placer

Resources, by J. Fowler and C. Miller, 1985, 69 pages. ($10.00)

NOTE: As of January 1986, all new open file reports will have a report number which will be assigned sequentially based upon the year the report is received by the Department.

OFR 86-010	Study of Markets for Aggregate Materials accessible from Nova Scotia and New Brunswick, by ADI Limited. ($10.00)
OFR 86-012	A Study of Industrial Minerals Used in Oil and Gas Exploration on the Eastern Canadian Offshore, by Jacques, Whitford and Associates and Cleland, Dunsmuir Consulting Limited. ($17.00)
OFR 86-013	Study of Markets for Silica and Silica Sands Accessible from Nova Scotia and New Brunswick, by ADI Limited. ($10.00)
OFR 86-019	Compilation of drillhole information from open assessment reports available to the end of December, 1985: Central Nova Scotia - map sheets 11D, 11E. ($10.00)
OFR 86-020	Compilation of drillhole information from open assessment reports available to the end of December, 1985: Eastern Nova Scotia - map sheets 11F, 11G, 11J, 11K, 11N. ($10.00)
OFR 86-021	Compilation of drillhole information from open assessment reports available to the end of December, 1985: Western Nova Scotia - map sheets 20O, 20P, 21A, 21B, 21H. ($10.00)
OFR 86-025	The Gypsum Industry in Nova Scotia - Present Status and Future Prospects, by R. E. Wright and J. H. Brown. Prepared for Nova Scotia Department of Mines and Energy by Center for Resource Studies, Queen's University, 1985, 125 pages. ($15.00)
OFR 86-039	Agricultural Gypsum Project, by P. Luke, 1986, 9 pages. ($3.00)
OFR 86-054	The U.K. Experience on the Effects of Offshore Sand and Gravel Extraction on Coastal Erosion and the Fishing Industry, by R. Warren Drinnan and D. G. Bliss, Dobrocky Sea Tech Limited, August 1986, 90 pages. ($10.00)
OFR 87-002	Market Analysis for New Brunswick, Nova Scotia and Newfoundland Dimension Stone, by the DPA Group Incorporated in association with Jacques Whitford & Associates Limited, 1987, 66 pages. ($10.00)
OFR 87-005	Report on the Potential Stone Quarry, MacKenzie Farm, Hardwood Hill, Pictou County, Nova Scotia, by G. Dickie, 1986, 37 pages. ($5.00)
OFR 87-023	Report on the English Property (McKeen Quarry), Pictou County, by G. B. Dickie, 1987, 12 pages. ($5.00)
OFR 87-027	Potential Crushed Stone Deposits on Tidewater in Nova Scotia, by G. B. Dickie, 1987, 15 pages. ($5.00)
OFR 87-032	Sulphur in Nova Scotia: Pugwash and Hilden Occurrences, by D. C. Carter, R. C. Boehner and G. C. Adams, 1987, 7 pages. ($5.00)
OFR 88-013	A Study of U. S. East Coast Industrial Mineral Markets for New Brunswick, Newfoundland and Nova Scotia, by Metals Economics Group, 1988. Prepared for Mineral Policy Sector, Energy Mines and Resources Canada, 286 pages. ($15.00)
OFR 88-039	Marine Transport Study for Nova Scotia, by Leslie MacIntyre Maritime Associates Inc., May 1988. Prepared for Mineral Policy Sector, Energy, Mines and Resources Canada, 38 pages. ($5.00)
OFR 88-040	Aggregate Market Study for New Brunswick and Nova Scotia, by ADI Limited, 1988. Prepared for Mineral Policy Sector, Energy, Mines and Resources Canada, 309 pages. ($17.00)
OFR 88-055	Multielement Ratings Maps for Meguma Zone Lake Sediments, by P. J. Rogers, 1989, 34 pages, 3 maps. ($5.00)
OFR 88-056	An Assessment of the Hydrocarbon

and Compressed Air Storage Potential of Nova Scotia Salt Deposits, by Nolan, Davis & Associates Ltd., 1988, 195 pages. ($20.00)

OFR 88-057 Gypsum, Anhydrite Potential, Meadows Road Area, Cape Breton County, by G. Adams, 1988, 29 pages. ($5.00)

OFR 88-059 Interpretation of Till Geochemical Data in Nova Scotia, Canada, Using Mapped Till Units, Multi-Element Anomaly Patterns, and the Relationship of Till Clast Geology to Matrix Geochemistry, by R. G. Turner and R. R. Stea, 1988, 39 pages. ($5.00)

OFR 88-063 An Assessment of the Hydrocarbon and Compressed Air Storage Potential of Nova Scotia: A Summary, by Nolan, Davis & Associates Ltd., 1988, 22 pages. ($3.00)

OFR 89-001 Lithogeochemistry of the Eastern Portion of the South Mountain Batholith, Nova Scotia, Map Sheets 11D/05, 11D/12, 11D/13, 21A/09, 21A/10, 21A/15, 21A/16 and parts of 21H/01 and 21H/02, by L. J. Ham, S. W. Marsh, M. C. Corey, R. J. Horne and M. A. MacDonald, 62 pages, 2 maps. ($15.00) (Disk copy of geochemical data $5.00)

OFR 89-003 Open file report on selected mineral occurrences of the Antigonish area, NTS 11E/08, 09 and 16, by K. E. Northcote, G. DeMont and A. Armitage, February 1989, 184 pages plus tables. ($15.00)

OFR 89-004 Open file report on selected mineral occurrences of Southern Cape Breton Island, Nova Scotia, NTS 11F/10, 11F/15, 11F/16, 11K/01, 11K/02, by K. E. Northcote, G. DeMont and A. Armitage, March 1989, 94 pages plus tables. ($10.00)

OFR 89-005 Open file report on selected mineral occurrences of the Cobequid area, Nova Scotia, NTS 11E/05, 11E/06, 11E/10, 11E/11, 11E/12, 21H/07, 21H/08, by K. E. Northcote, G. DeMont and A. Armitage, March 1989, 180 pages plus tables. ($15.00)

OFR 89-006 Summary report on quarry stone used in the construction of Dominion Building, Halifax, N. S., by G. B. Dickie, 1989, 16 pages. ($3.00)

OFR 89-007 Geochemical analyses of bulk stream sediment samples from northern Nova Scotia, by R. F. Mills, 1989, includes many tables and 3 sample location maps, scale 1:250 000. ($40.00)

OFR 90-004 Heavy mineral till geochemistry (tin) of the eastern and central South Mountain Batholith, by P. W. Finck, F. J. Boner and R. M. Graves, 1990, 21 pages, 3 maps, scale 1:250 000. (10.00)

OFR 90-008 Quaternary geology of Nova Scotia; Guidebook for 53rd annual Friends of the Pleistocene Field Excursion, May 25-28, 1990, 85 pages, 61 Figures. (11.00)

OUTSIDE PUBLICATIONS AND MAPS AVAILABLE FOR PURCHASE

OP-1 Malagash Salt, compiled and edited by J. R. MacQuarrie, c.1975, 1981. ($5.00)

Geological Association of Canada/Mineralogical Association of Canada Guidebooks for Field Excursions (Fredericton, May 15-17, 1985).

OP-2 Trip No. 1 Appalachian Geotraverse (Canadian Mainland); J. D. Keppie, K. Currie, J. B. Murphy, et al., 181 pages. ($15.00)

OP-4 Trip No. 10 Igneous and Metamorphic Geology of the Cape Breton Highlands; S. M. Barr, R. A. Jamieson, R. D. Raeside. ($5.00)

OP-5 Trip No. 11 Turbidite-Hosted Gold Deposits, Meguma Domain, Eastern Nova Scotia; P. K. Smith, S. J. Haynes, B. E. Jones. ($7.00)

OP-6 Trip No. 14 Lithostratigraphic, Physical Diagenetic and Economic

	Aspects of the Pennsylvanian Permain Transition Sequence of Prince Edward Island and Nova Scotia; H. W. van de Poll, J. R. Degrace, R. J. Ryan. ($7.00)
OP-7	Basins of Eastern Canada and Worldwide Analogues, Programme with Abstracts, Basins of Eastern Canada and Worldwide Analogues Symposium, August 13-15, 1986, Halifax, Nova Scotia, 132 pages. ($8.00)
OP-8	Atlantic Geoscience Society, Special Publication Number 3. Occupational Safety in the Geosciences, Programme with Abstracts: A Seminar and Panel Discussion on Safety-Related and Their Legal Topics Concerning Geoscientists and Their Work Environments, Organized by the Atlantic Geoscience Society, and Co-Sponsored with the Department of Geology, Dalhousie University, The Nova Scotia Chamber of Mineral Resources, The Atlantic Provinces Council on the Sciences, and Geomarine Associates Limited, Dalhousie University, Halifax, Nova Scotia, September 25, 1985, 100 pages. ($2.00)
OP-9	Atlantic Geoscience Society, Special Publication Number 4. Carboniferous-Jurassic Sedimentation and Tectonics: Minas, Cumberland and Moncton Basins, Nova Scotia and New Brunswick, by R. C. Boehner, J. H. Calder, D. C. Carter, H. V. Donohoe, Jr., L. Ferguson, R. K. Pickerill, and R. J. Ryan; a Field Trip Guidebook from the Basins of Eastern Canada and Worldwide Analogues Symposium, Halifax, August 1986, 122 pages. ($8.00)
OP-10	Atlantic Geoscience Society, Special Publication Number 5 (CSPG Memoir 12). Sedimentary Basins and Basin-Forming Mechanisms, edited by C. Beaumont and A. J. Tankard; from Basins of Eastern Canada and Worldwide Analogues Symposium, Halifax, August 1986, 527 pages. ($70.00)
OP-11	Atlantic Geoscience Society, Colloquium '88, Antigonish, N. S. (Abstracts of Papers). ($4.00)
OP-12	Contributions to the geology of the Meguma Terrane, Nova Scotia, edited by J. D. Keppie. Special issue of Maritime Sediments and Atlantic Geology, v. 22, no. 1, 1986, 135 pages. ($10.00)
OP-13	Quaternary Glaciations, Geomorphology and Sea Level Changes: Bay of Fundy Region; NATO Advanced Study Institutes Programme, International Advanced Course on Late Quaternary Sea Level Correlations and Applications, July 19 to 30, 1987, Halifax, Nova Scotia; Symposium Field Guide, 79 pages. ($10.00)
OP-14	The Mining Society of Nova Scotia 1887-1987, by D. Pigot. Published by the Mining Society of Nova Scotia, June 1987, 125 pages. ($20.00) (Paperback: $10.00)
OP-15	Contributions on the geology of granitoid and host rocks, Meguma Terrane, Nova Scotia, edited by D. J. Kontak and S. M. Barr. Special issue of Maritime Sediments and Atlantic Geology, v. 24, no. 1, 1988, 121 pages. ($10.00)

SAMPLE CATALOGUES

SC 89-1	Nova Scotia's Dimension Stone for Designers, Developers, Quarries, 1989. ($100.00)